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PB-286 920

Upgrading Trickling Filters

(U.S.) Environmental Protection Agency, Washington, DC

Jun 78

United States
Environmental Protection
Agency

Office of
Water Program Operations (WH-547)
Washington DC 20460

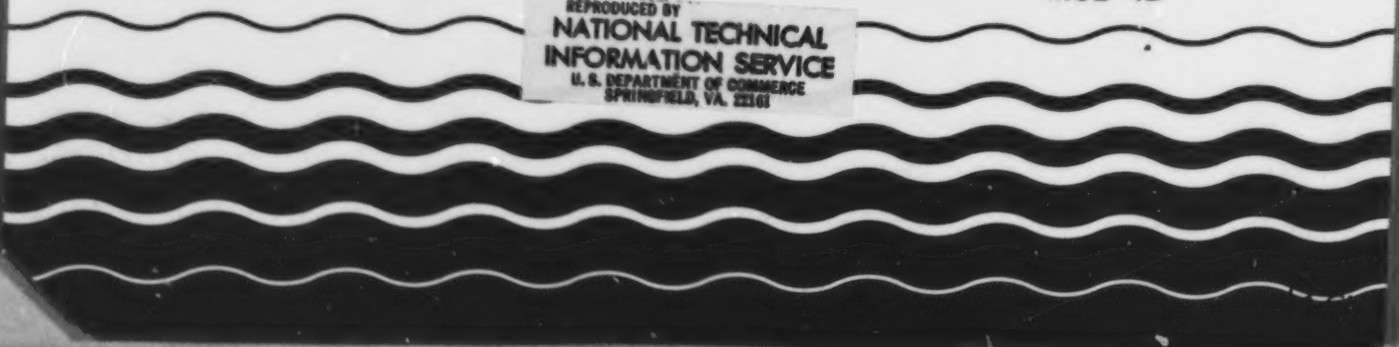
June 1978
430/9-78-004

PB 286920

Water

Upgrading Trickling Filters

MCD-42



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TECHNICAL REPORT DATA

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1. REPORT NO. 430/9/78-004	**2.**	**3. RECIPIENT'S ACCESSION NO.** PB286920
4. TITLE AND SUBTITLE "Upgrading Trickling Filters"		**5. REPORT DATE** June 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Donald Pierce		**8. PERFORMING ORGANIZATION REPORT NO.**
9. PERFORMING ORGANIZATION NAME AND ADDRESS Municipal Construction Division Office of Water Programs Washington, D.C. 20460		**10. PROGRAM ELEMENT NO.** 2BG647
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Office of Water Program Operations U.S. Environmental Protection Agency Washington, D.C. 20460		**13. TYPE OF REPORT AND PERIOD COVERED** technical report
		14. SPONSORING AGENCY CODE 700/02

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Trickling filters offer advantages of lower energy needs and relative ease of operation. This report presents operating results from more than 100 existing trickling filter treatment plants and makes some general observations concerning the overall successful performance of these systems. While the report is not a complete analysis of these types of systems, it does indicate that, when properly designed, constructed and operated, trickling filters are an alternative which is worthy of further consideration in meeting the discharge requirements of the law. The basic thrust of the report is that trickling filters, often in combination with other treatment techniques, should be considered for new facilities as well as for continued use in plants where they presently exist.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water Pollution Control	Trickling filters	

18. DISTRIBUTION STATEMENT Release to the Public	**19. SECURITY CLASS** *(This Report)* unclassified	**21. NO. OF PAGES** 139
	20. SECURITY CLASS *(This page)* unclassified	**22. PRICE** PC A07

EPA Form 2220-1 (9-73)

EPA 430/9-78-004 MCD-42

TECHNICAL REPORT

UPGRADING TRICKLING FILTERS

BY

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JULY 1978

PREPARED FOR

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS
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FOREWORD

In 1972, Congress set into motion a comprehensive program to restore and maintain the Nation's rivers and lakes by passage of amendments to the Federal Water Pollution Control Act. The recent Clean Water Act of 1977 reaffirmed this commitment by adopting additional amendments which strengthened a number of the provisions of the law.

A major element of the country's clean water strategy is to improve the quality of the effluent discharged from municipal wastewater treatment works. Federal funds for the construction of municipal wastewater treatment works provide the cornerstone on which the municipal program is built. With the availability of large amounts of Federal grant funds, there may be a tendency to choose capital intensive and more complex newer technology. This is not to say that such technologies will not be needed to cost-effectively achieve many of our objectives. However, certain "tried and true" systems such as trickling filters can also play an important role in these efforts.

Trickling filters offer advantages of lower energy needs and relative ease of operation. This report presents operating results from more than 100 existing trickling filter treatment plants and makes some general observations concerning the overall successful performance of these systems. While the report does not pretend to be a complete analysis of these types of systems, it does indicate that, when properly designed, constructed and operated, trickling filters are an alternative which is worthy of further consideration in meeting the discharge requirements of the law. The basic thrust of the report is that trickling filters, often in combination with other treatment techniques, should be considered for new facilities as well as for continued use in plants where they presently exist.

It is only by making full use of all of the available alternatives that we will be able to ensure that the best solutions to our pollution problems are found. We are confident that trickling filters can continue to provide an important contribution to our Nation's water pollution control efforts.

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UPGRADING TRICKLING FILTERS -

A STUDY OF OVER 100 PLANTS

by

Donald M. Pierce

Findings of Fact and Conclusions

The following findings resulted from examination of records of operation, plant visitations and discussions with operating staffs of trickling filter plants in Minnesota, Michigan, Pennsylvania, Wisconsin and North Dakota. A total of 104 plants were selected for study on the basis of completeness and duration of operational records and the excellent balance they provided in size of installation, variety of facilities, and operational modes including sludge treatment and disposal. Plants providing further treatment of the trickling filter plant effluent were selected as representative of the processes employed both in facility and performance under typical operating conditions.

1. Process Capability

- Trickling filter plants in their simplest combination of unit processes for grit removal, screening, sedimentation, filters and sludge treatment and disposal are capable of a high degree of treatment when given ordinary and reasonable attention.

- Single-stage filter plants are capable of 90% removal of BOD_5 and suspended solids from the raw wastewater but may remove as little as 60%. Statistically, for the 69 plants studied, the most probable values of plant effluent are 36 mg/l BOD_5 with 83% overall removal and 32 mg/l suspended solids representing 84% overall removal. There is 90% probability that BOD and suspended solids removal will not be less than 74%.

- Removal of BOD_5 at two-stage filter plants is significantly higher than at single-stage plants. The most probable value from 20 plants studied was close to 90% removal and 25 mg/l.

- Removal of suspended solids at two-stage trickling filter plants is at about the same level as at single-stage plants.

- Many single-stage and two-stage plants can be loaded much higher, both hydraulically and organically, without reduction of effluent quality.

2. Factors Affecting Performance

Loading Rates - Hydraulic and organic loadings at the 76 plants for which adequate information was available indicate that the degree of removals of BOD_5 and suspended solids appeared to be relatively independent of the magnitude of the loadings within the ranges studied for both single and two-stage filter systems. Hydraulic loadings generally ranged from 100-320 gal/day/ft^2 (5-15 MGAD) for single-stage plants. Slightly higher loadings were typically observed for two-stage filter systems although some were significantly higher. BOD_5 loadings for both types of systems were usually in the 10-60 lbs/100 ft^3 range, although some values were much higher.

Low Temperatures - Relatively low raw wastewater temperatures during winter generally reduced overall plant removal of BOD by about 1/3 at 9 plants studied. These adverse effects can be reduced by providing protection such as housing, windbreaks, reduction in settling tank detention time and reduced recirculation to reduce heat loss.

Recirculation - No observable relationship was found between quantity of flow recirculated to the filters and extent of removal of BOD_5 or suspended solids. Plants with no recirculation or very low rates of recirculation appeared to perform as well as those with recirculation of up to three times the raw wastewater flow.

Size - Small plants serving a few hundred people were observed to operate as effectively, as measured by BOD_5 and suspended solids removal, as similar plants serving several thousand.

Type of Trickling Filter Media - Rock media and plastic media were observed to provide similar levels of treatment for equal loadings per unit volume of media.

Clarifier Overflow Rates - Detailed information on 23 plants where reliable data were available indicated similar BOD and suspended solids removal at plants with final clarifier overflow rates of 1000 gpd/ft^2 and higher compared with plants with rates of 500 gpd/ft^2 or lower. This was observed at both single-stage and two-stage filters and those where chemical treatment was provided.

3. Upgrading by Series Operation

- Conversion from a single-stage to a two-stage system without adding filter media can greatly improve effluent quality, as measured by BOD_5 -- usually by about 50%.

4. Upgrading with Chemicals

- Chemicals applied prior to primary sedimentation increased removal of BOD_5 and suspended solids from raw sewage to clarifier effluent by 34% to 59% and increased suspended solids removal by 51% to 71%. This greatly reduces loadings on filters and final settling tanks.

- Chemical treatment with metal salts and polymers (intended primarily for removal of phosphorus) upgraded single-stage filter system effluents from an average concentration of 36 mg/l BOD_5 to 21 mg/l. Similarly effluent suspended solids were reduced from 32 mg/l to 19 mg/l. Similar performance was found with lime.

- The adverse effects of extremely cold sewage and air temperatures on removal of BOD and suspended solids are less at plants where chemicals are used.

- Although chemical treatment with metal salts and polymers greatly increases the solids loadings on sludge digestion and dewatering facilities, additional or modified solids processing facilities were not needed at the plants studied. Increased quantities of digester supernatant and vacuum filter filtrate are treated with the raw sewage with no particular difficulty observed.

- Physical alterations for the storage, application and mixing of chemicals and polymers are quite simple and can be provided at a reasonable cost.

- The cost of chemicals is not prohibitively expensive.

5. Upgrading with Supplementary Processes

- Fine media filters: Several typical installations of fine media filters were studied. The types of filters were mixed media pressure filters with backwash; fine mixed media gravity filters with backwash; sand gravity filters with backwash; and gravity feed intermittent sand filters with underdrains. Each type of installation markedly upgraded the quality of the trickling filter effluent. All of the gravity systems produced effluents less than 10 mg/l BOD_5 and suspended solids.

- Ponds: Wastewater treatment ponds are quite commonly used for upgrading trickling filter effluent. Three typical installations were studied. Single-stage filter plant effluents were upgraded to about 95% BOD_5 removal. There are strong indications that ammonia nitrogen was almost completely removed.

- Operational Considerations: Fine media filter systems and lagoons are relatively easy to control and simple to operate effectively.
- Activated Sludge: Performance of six plants using activated sludge to upgrade trickling filters was studied. Removal of BOD_5 averaged 95% and suspended solids 93%.

6. Selection of Upgrading Techniques

Trickling filters can readily be supplemented by treatment processes such as fine media filtration, ponds and activated sludge to produce high quality effluents. These processes, together with conversion of single-stage to two-stage filters and/or chemical treatment provide the designer with great flexibility for upgrading existing trickling filter plants to the desired performance level or to design new trickling filter systems for a wide range of specific conditions and requirements.

BACKGROUND

The purpose of this report is to present information on various current trickling filter operations which indicates that these systems are successfully operated, and in many cases, can be economically upgraded to meet the requirements of the Federal Water Pollution Control Act Amendments of 1972.

For over 40 years, the trickling filter has been widely recognized in this country and abroad as a dependable, reliable biological treatment process, well suited to the needs of small to medium size communities. In recent years, the use of this once popular system has diminished in comparison to other biological and physical processes. The waste stabilization lagoon proliferated greatly during the fifties and sixties in small communities and activated sludge in its several modes became quite generally the process of choice in medium to large municipal installations.

Decreased popularity of the trickling filter has been attributable principally to the well recognized failure and real inability of some existing installations to produce the high quality of effluent now required to meet the national water quality goals. Moreover, there seems to be a wide diversity of opinion in the field and laboratory as to parameters for design and operation to produce specified effluent quality within the entire range of performance of which the process is capable. Designers, public works officials, and regulatory agency personnel alike, are often hesitant to seriously consider trickling filters because of a lack of confidence in precise design criteria.

Several critical evaluations in the available technical literature on trickling filters confirm this observation. In the comprehensive Literature Search and Critical Analysis of Biological Trickling Filter Studies (EPA Project No. 170 50 DDY), summarizing the essence of 5665 references, the authors observe that it is well documented that there is no well defined theory of design and operation generally accepted by the principal investigators in the field. Examples noted are controversy over the effects of recirculation rates and points of recirculation, performance relationships with variations in hydraulic and organic loadings, types of media, depths of media, single stage vs. two-stage operation, with or without intermediate settling, capability to treat specified industrial wastes and still other considerations. The authors confirm the finding of others that a great many investigators have developed mathematical models for predicting performance with significant differences in factors included and in the performance predicted under similar conditions. It was observed that in-depth mathematical investigations have the tendency of losing their usefulness to the non-mathematically oriented practioner, and it is very unfortunate that these valuable studies have not been correlated with the vast operator experience available. It is further noted that engineers place more confidence on field or full-scale investigations and relationships derived therefrom than from laboratory data, with the recognized limitations of uncontrollable environmental conditions, variable waste sources and problems in sampling, analyzing and interpreting the data.

On the positive side, the trickling filter is credited with a degree of reliability in performance, recovery capability from shock loads, durability of process elements and relatively low power requirements not characteristic of activated sludge and other competing processes. And, very importantly, for small and medium size communities, the level of skill and technical know-how and size of operating staff required for continuously effective management and operation of the process is generally considerably less for trickling filters than for activated sludge and certain physical/chemical processes.

Reliable estimates set the number of municipal trickling filter installations in this country today at about 4000. The report indicates that many of these trickling filter systems are successfully providing secondary and higher levels of treatment. It must be recognized, however, that a portion of these installations do not meet current requirements for effluent quality based on 30 mg/l of BOD_5 and suspended solids and that some discharge to waters to which stringent water quality standards apply.

NEED FOR EXTENSIVE FIELD STUDIES

There is a need to assess the capability of the trickling filter process in all of its customary flow patterns and ranges of loadings by a close and thorough examination of a sufficient number of full scale field installations to accurately evaluate their performance. It is particularly important today to identify methods by which existing installations have been or can be modified in a cost-effective manner to produce higher quality effluents and to determine the extent of predictable improvement by such methods. Recognition of these needs prompted the undertaking of this study.

Review of the technical literature and study of the comprehensive Search and Critical Analysis of Biological Filter Studies, Vols. 1 and 2, reveal a surprising paucity of long period operational data with pertinent design features. Practically, there is not sufficient information from these sources to enable the reader to relate loadings and operational modes and methods with predictable performance. This is not to say that such information does not exist. Indeed, operators of trickling filter plants at hundreds of municipal installations have recorded vital data and valuable observations routinely. Some state regulatory agencies have required monthly submission of such key information as temperature, flow, BOD, suspended solids, volatile suspended solids, pH, recirculation rates, quantity and quality (moisture and volatile content) of sludge pumped, and pertinent information on digested sludge and supernatant. In addition, notes on operational and maintenance problems and practices are also available in many cases. Unfortunately, much of this highly valuable information is stored without abstracting, analyzing and keeping key data and other facts for the future use of the municipality, their designers and others concerned with its practical application. Unusual performance, either on the high or low side, often continues with little appreciation of the peculiar circumstances responsible for its departure from what is considered to be normal. Only occasionally is a case history recorded in the literature which includes in-depth performance studies. Such articles usually pertain to an installation where either an unusual or unique problem is identified, a specific industrial waste is treated or a specific design feature is highlighted. Seldom are the data reported of sufficient duration or confirmed by other similar installations and operational procedures to establish its predictable performance elsewhere. Quite commonly, the data is reported to confirm or support research studies conducted on laboratory or pilot plant scale.

The obvious need, therefore, was to collect performance data produced and recorded by plant operators at a sufficient number of installations, representative of what exists in municipal installations today, to establish the performance capability of the process in a wide range of facility combinations, loadings and operational modes. An equally important objective was to make in-depth studies at several plants with special design features or operational methods which illustrate methods for upgrading the quality of the effluent at existing installations.

AN OVERVIEW OF 104 PLANTS

A broad overall study was made of 104 plants in four northern states which included in-depth studies at 28 of these.

Selection Criteria

For the broad overall study, the following criteria were established and followed:

1. Location - a northern state or states having wide seasonal variations in both air and sewage temperatures.
2. Study all municipal trickling filter plants in the selected state or states for which desired data are available - not a selected few to illustrate a principle or method.
3. Study of typical plants in other states having more moderate climate.

For the in-depth studies, plants were to be selected where:

1. Operational data, including laboratory analyses are known to be dependable and to be developed and recorded by well-qualified operators and technicians.
2. Facilities and their operational patterns have certain features believed to have special promise.
3. Facilities are in good condition and well-operated.
4. Facilities include modifications for upgrading performance and have good operational data both before and after modifications were installed.
5. Chemicals have been added for at least a year for removal of phosphorus with concurrent improvement in removal of BOD and suspended solids and where performance records are available for significant periods both before and after the chemical additions.
6. Facilities contain special features and follow practices similar to those at plants described in 4 and 5 above.

Plants Selected

Plants in Minnesota were selected for the broad overall study. The trickling filter has been a popular biological process in this state for many years providing a typical variety of design features and loadings, varying from a single Imhoff tank followed by a single fixed nozzle filter without recirculation to installations with several primary settling tanks, two or more filters with rotary distributors and two or more final settling tanks. Several methods of recirculation are employed at various rates. Loadings, hydraulic and organic, range from very low to very high but mostly they are in the moderate range. Media, usually rock but also including tile and some other materials, are of varying shapes, sizes and degrees of uniformity.

Wastewater characteristics are quite representative of the typical range of municipal wastes applied to trickling filters. In some communities, the wastes are very dilute as a result of considerable infiltration and inflow to the sewer system; others are above normal in strength as measured by BOD_5 and suspended solids, reflecting admixtures of wastes from milk and cheese processing plants, canneries, slaughter houses and meat packing facilities.

Operating staffs are quite typical with respect to experience, capability and motivation. A sound practical training program, in conjunction with an operator certification program, has been conducted for many years by the Minnesota Pollution Control Agency and its predecessor agencies. This and a close relationship between the Agency district personnel and the operators has encouraged and fostered good operational practice. It is to be noted, however, that a large percentage of the small municipalities contract with commercial laboratories to perform chemical and bacteriological tests. These data are submitted to the Agency in addition to other physical and operational data assembled by the plant operating staff.

The 1973 Annual Summary of Trickling Filter Study Results prepared by the Minnesota Water Pollution Control Agency lists 163 municipal plants. Data are provided on year of construction, annual averages for design and actual flow, and BOD_5, total coliform, fecal coliform, total phosphorus and Kjeldahl Nitrogen for both the plant influent and effluent. These annual summaries are based on monthly averages abstracted by their staff personnel from operational reports submitted by the municipalities and supplemented by Agency field sampling and analyses.

As the study of Minnesota plants progressed, it was found that a large number of plants did not have sufficient data to permit the depth of analysis desired. Many plants had incomplete flow data, or none at all, for the year studied. At others, laboratory data were lacking for several months. Quite a large number of these trickling filters were followed by activated sludge, sand filters or stabilization ponds. In these cases, the data were for the final effluent rather than the trickling filter effluent. These plants were not used in this study but all others with sufficiently complete operating data were included as recorded in Table 1.

Typical plants in Michigan and Pennsylvania were selected for comparison of performance with the Minnesota plants. A few scattered installations in North Dakota and Wisconsin selected for in-depth study are also included in this tabulation.

Plants selected initially for in-depth study were located in Michigan. Design data and monthly operation reports were made available and personal contacts with agency personnel and plant operating staffs provided a depth of knowledge and interpretation most valuable to an objective and realistic evaluation of performance in relation to facility and management techniques.

All of the Michigan plants were under the control of resident operators certified as to competency by the State Agency. Operational programs were adequate and staffs were observed to be capable and industrious. Laboratoy analyses were generally performed several times weekly on composited samples by well-trained plant technicians. In some plants these analyses were performed daily. This provided an excellent opportunity to observe day to day results and trends and to note cause and effect relationships of loadings, operational modes, temperature variations and other variables.

Of the 22 Michigan plants studied, 14 have routinely applied chemicals and polymers for removal of phosphorus for at least one year under a program requiring removal of at least 80% total phosphorus. Of those with chemical treatment, nine use rock media and five use plastic sheets. At six of these plants, laboratory data were available for a substantial period before chemical additions began and for over a year after chemical treatment became well established. This provided an excellent opportunity to evaluate the effect of chemical treatment as here employed on removal of BOD_5 and suspended solids.

It was also considered desirable to study the extent of improvement in BOD_5 and suspended solids by the second filter and its settling tank in a two-stage system. Only one installation in Michigan had the necessary information. However, one additional plant in both Wisconsin and Minnesota was found to have this kind of data. Each of the three were considered to be representative of the process and generally similar to 19 other two-stage plants listed in Table 1, where data on the first stage portion were lacking. This provided a good opportunity to assess the improvement to be expected in series compared with parallel operation.

Plants were sought which utilize additional treatment processes to improve the quality of effluent of the trickling filter and its final settling tank. Although many facilities of this kind were located, only eight routinely sample the settling tank effluent following the trickling filter when the additional treatment facilities are in operation. Good reliable data were obtained from each of these eight plants. Four of the eight use sand or mixed media filters, two use ponds, one uses an aerated lagoon followed by ponds and one uses activated sludge. An opportunity was afforded to compare overall plant removal at these locations with several others using similar facilities but lacking the trickling filter effluent data.

Study Methods

All information used in the study was obtained from the responsible state regulatory agency or plant superintendant or both. Physical data such as number and capacities of treatment units and their arrangement was generally obtained from the state agency which approved the design. Frequently specific additional information of this kind was also obtained directly from the plant personnel. Performance data were furnished in most instances by the regulatory agency in the form of monthly operation reports or abstracts from them. Many of the plant superintendants were contacted by personal visit at the plant, telephone or letter to obtain a clear understanding of pertinent facts particularly with respect to operation and maintenance practices and results.

The close cooperation and great interest of all state agency personnel and of the many plant personnel contacted provided a great amount of useful information and a degree of understanding not otherwise obtainable.

Data Recorded and Analyzed

Data from 98 plants selected for study are summarized in Table 1*. All values represent annual means of monthly mean values. Terms used in headings have the following meaning:

- 1970 Pop: Population by 1970 Census of the community served - not necessarily indicative of the population connected to the sewer system.

- Sewage Flow-MGD: The average rate of raw sewage flow before additions of recycled flows within the plant.

- Raw (BOD_5 and Suspended Solids): Wastewater in plant inflow before any in-plant additions.

- PE: Effluent from the primary settling tank. Actual values unless indicated by an asterisk (*). Asterisk denotes assumed value of 35% removal compared to raw wastewater.

- FE: Effluent from the settling tank following trickling filters.

- Filter Loading: $R = \frac{Q_1 - Q}{Q}$ where Q_1 is total flow through the filter and Q is raw sewage flow.

- MGAD: Million gallons per acre of media per day.

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* Plus 6 plants with activated sludge for additional treatment (Table 28).

Since data were not readily available at many of the plants on the quality of effluent from the primary settling tank(s), as measured by BOD_5, these values at such plants were calculated on the basis of 35% removal of the raw wastes entering the plant. It will be noted from Table 20 that removal at 16 plants for which extensive data were analyzed ranged from 18% - 51% with a mean value of 34%.

For all plants where in-depth studies were made, the monthly mean values for 12 months or longer were abstracted and calculated from plant operation reports. Summary data was recorded by month for quantity of flow (MGD), raw sewage temperature (^{o}F), BOD_5 and suspended solids in plant influent (raw), primary settling tank effluent (PE), final settling tank effluent following the trickling filters (FE). Where chemicals are applied for removal of phosphorus, pertinent information on rates of chemical feed and the concentration of total phosphorus in plant influent and plant effluent is indicated when available. In the appendix, data sheets have been prepared to provide information on flow patterns, loading rates and capacities of various units, including filters, final settling tanks and sludge digesters. Methods of sludge management of digested sludge, digester supernatant and vacuum filter filtrate are also indicated.

Data are inspected to compare hydraulic and organic loadings and removal of BOD_5 and suspended solids; effects of recirculation on plant performance; comparisons of single-stage with two-stage filters in overall performance throughout the range of loadings experienced; effects of variations in temperature of the raw sewage; comparison of performance of filters with rock media vs. plastic media; effects of chemical additions (usually iron or aluminum salts and polymers for the primary purpose of removing phosphorus) on removal of BOD_5 and suspended solids; effects of various methods of sludge treatment and disposition on removal of BOD_5 and suspended solids; and the extent of improvement provided in plant effluent quality by several additional treatment processes following trickling filters.

Data are summarized also on facilities used and the dosage rates of chemicals, with some indications of the pertinent costs.

Patterns in performance are visible in the summary data derived from these studies of trickling filter plants. These patterns are considered categorically as single-stage and two-stage filters, with some comparison of effects of hydraulic and organic loadings and effects of chemical treatment. Several methods of upgrading are examined. These include conversion of single-stage to two-stage alignment, addition of metal salts and polymers and several processes for further treatment of trickling filter plant effluents.

Single-Stage Filters

The most common design of trickling plants at municipal installations in operation today throughout this country utilizes single-stage filters. Usually plant units consist of screening, grit removal, raw sewage pumping, sedimentation, one or two trickling filters operated in parallel, a final settling tank and the plant outfall sewer. The effluent may or may not be disinfected. Sludge from the settling tanks is most commonly pumped to heated sludge digestion tanks, often followed by unheated sludge digestion or storage tanks. Digester supernatant is most commonly discharged to the raw sewage before primary sedimentation. Digested sludge is commonly discharged periodically to open sludge drying beds but at some locations is discharged to sludge lagoons or hauled to land application areas, usually for agricultural purposes. In some of the larger plants, vacuum filters are used for sludge dewatering before final disposition. A few installations have Imhoff tanks for sedimentation and sludge digestion, obviating the need for cycling supernatant through the plant.

Hydraulic Filter Loading Rates

Hydraulic loadings reported in Table 1 represent average daily rates of flow in MGAD and in gpd/ft^2 (annual average of monthly values). Recirculated flow is noted under column R. No attempt was made, except where specifically noted, to determine instantaneous pumping rates or the capacity of the pumps most commonly in service.

Table 2 shows the range of hydraulic loading and the relationship of hydraulic loading to removal of BOD$_5$ for the 61 plants studied. These data are plotted in Fig. 1. No observable difference is found either in the concentration of BOD$_5$ in the plant effluent or percent removal thereof through these ranges of hydraulic loadings. Although most of these loadings are below 500 gpd/ft^2 (13 MGAD of media), three are above this range. One is as high as 1630 gpd/ft^2 (71 MGAD) with an effluent BOD$_5$ of 37 mg/l and 80% removal. Visual examination of the recirculation ratios in Table 1 and Fig. 2 in terms of BOD removal does not reveal any observable differences in performance between systems with no recirculation, recirculation ratios of 0.1 - 0.3 or those from 1.0 - 3.0.

Table 3 and Fig. 3 are plots of the hydraulic loadings vs. removal of suspended solids by the total plant in these same plants. Effluent concentrations (mg/l) of suspended solids and average removals thereof by the entire plant compare quite closely with BOD$_5$ values. There is some indication that removals may be somewhat less when hydraulic rates exceed 400 gpd/ft^2 although there are not only a relatively small number of plants in this loading range on which this observation is based. No observable relationship between recirculation ratios and solids removals is detectable from these data.

Organic Filter Loading Rates

Values for BOD$_5$ (mg/l) again represent the annual average of monthly values.

Table 4 and Fig. 4 show a marked similarity in performance as reflected by BOD$_5$ (FE) and percent removal through the plant for all BOD loading ranges. Although most of these plants have loadings under 60 lbs/1000ft^3 of media, eight of the plants have loadings in the 61-140 lbs range with no perceptible difference in BOD removal.

*Calculated as
65% of raw
sewage strength

NR = No Record

TABLE 1A

REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS BY TRICKLING FILTERS SINGLE STAGE

Mn..........Minnesota
Mi...........Michigan
Pa...........Pennsylvania
N.D........North Dakota
Wi..........Wisconsin

MUNICIPALITY State	1970 Pop.	Sew. Flow MGD	BOD$_5$					SUSP. SOL.			FILTER LOADING					
			Raw mg/l	PE mg/l	FE mg/l	% Rem. PE-FE	% Rem. Raw-FE	Raw mg/l	FE mg/l	% Rem. Raw-FE	Area Acres	Vol. 1000 cu.ft.	R	MGAD	Gals. per Day per sq.ft.	Lbs. BOD per 1000 cu.ft.
101. Mn	711	0.11	208	*135	22	84	89	119	23	81	0.065	22.6	0.2	2.1	48	6
102. Mn	1823	NR	309	200	42	79	86	164	27	84	0.064	17.0	0.4	NR	NR	NR
103. Mn	11,140	1.02	285	*185	59	68	79	NR	NR	NR	0.180	47.1	0.3	7.4	170	36
104. Mn		0.46	167	*109	27	75	84	185	31	83	0.076	26.5	0	6.1	140	16
105. Mn	11,667	2.10	142	* 92	26	72	82	192	40	79	0.360	125.6	NR	5.8	133	13
106. Mn	625	0.04	148	* 96	38	60	74	124	23	81	0.009	2.5	1.0	8.7	200	13
107. Mi		1.07	134	99	42	58	69	139	41	71	0.115	30.2	1.2	21.0	482	29
108. Mn	2467	0.53	392	*255	34	87	91	210	21	90	0.080	23.2	2.1	7.0	161	49
109. Mn	391	NR	464	*302	31	90	93	201	35	83	0.016	4.2	1.0	NR	NR	NR
110. Mi	1974	0.40	195	151	33	78	83	183	22	88	0.083	21.8	1.3	10.0	230	23
111. Pa		2.64	432	*280	41	86	91	252	45	82	0.811	185.6	NR	3.3	75	33
112. Mi	8244	0.77	224	119	63	47	72	256	59	77	0.10	26.5		7.6	174	29
113. Mn	5913	0.55	179	*116	31	73	83	111	21	81	0.360	9.5	0.4	21.2	487	55
114. Mn	525	NR	225	*146	75	49	67	280	61	78	0.007	1.9	NR	NR	NR	NR
115. Mn	794	0.51	300	*195	40	79	87	300	34	89	0.007	2.5	0	7.3	168	33
116. Mn	1851	2.06	185	*120	37	69	80	193	47	76	0.029	7.5	0	71.0	1630	275
117. Mn	5797	0.93	259	*168	40	76	85	243	37	85	0.216	71.4	0	4.6	106	18
118. Mn	1484	NR	320	*208	25	88	92	180	53	71	0.011	9.8	0.5	NR	NR	NR
119. Mn	2252	0.25	206	*134	27	80	87	300	33	89	0.009	2.3	1.0	55.3	127	122
120. Mn	588	0.03	162	*105	31	70	81	213	31	85	0.016	4.2	0	1.6	37	5
121. N.D.		5.86	220	*143	56	61	75	178	47	74	1.080	422	0.1	4.6	106	16
122. Mn	1130	0.14	387	*251	42	83	89	229	28	88	0.036	9.5	1.0	7.7	177	31
123. Pa	NR	0.36	215	*140	12	91	94	211	10	95	0.180	51.0	NR	2.0	46	8
124. Mn	939	0.17	201	*131	31	76	85	166	20	88	0.056	14.7	0	3.0	69	9
125. Mi	7728	1.28	138	91	32	65	77	178	38	79	0.36	94.3	0	3.6	83	10
126. Mn	6439	0.99	159	*103	16	85	90	166	17	90	0.078	20.5	1.0	12.6	289	41
127. Mn	1883	0.20	270	*175	52	70	81	349	44	87	0.045	13.7	0.2	5.2	119	21
128. Mn	1382	NR	167	*109	58	47	65	160	62	61	0.029	10.0	0	NR	NR	NR
129. Pa	NR	0.73	152	* 99	22	78	86	134	21	92	0.439	114.7	NR	1.7	38	5
130. Mn	567	0.15	258	*168	29	83	89	109	17	84	0.029	7.5	0	5.2	119	28
131. Mn	3142	0.20	270	*176	51	71	81	174	55	68	0.016	5.7	0	12.2	280	51
132. Mi	6314	0.94	104	65	23	64	77	150	21	80	0.09	22.8	0.3	13.5	310	22
133. Mn	1162	0.15	431	*280	66	76	85	296	43	85	0.022	7.9	NR	6.8	156	45
134. Mn	7467	1.40	187	*122	19	84	90	217	14	94	0.101	26.5	0	13.9	319	54

*Calculated as 65% of raw sewage strength

NR = No Record

TABLE 1B

REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS BY TRICKLING FILTERS TWO STAGE

MUNICIPALITY	State	1970 Pop.	Sew. Flow	BOD$_5$					SUSP. SOL.			FILTER LOADING					
				Raw	PE	FE	% Rem.	% Rem.	Raw	FE	% Rem.	Area	Vol.	R	MGAD	Gals. per Day	Lbs. BOD per
			MGD	mg/l	mg/l	mg/l	PE-FE	Raw-FE	mg/l	mg/l	Raw-FE	Acres	1000 cu.ft.			per sq.ft.	1000 cu.ft.
201.	Mn	6973	0.70	242	*157	26	83	89	341	55	84	0.072	25.4	0	9.7	225	36
202.	Pa		2.10	165	*107	20	81	88	180	15	92	0.231	64.5	NR	9.1	210	29
203.	Mn	3275	0.42	290	*188	31	84	89	107	27	75	0.110	28.9	2.0	11.3	260	8
204.	Mn	2619	0.30	134	* 87	9	90	93	204	16	92	0.104	27.3	3.0	11.4	260	8
205.	Mn	580	0.13	781	*508	40	92	95	541	42	92	0.027	7.2	0	4.7	108	74
206.	Mn	3104	0.41	405	*263	46	83	89	242	54	78	0.121	31.7	NR	3.4	78	29
207.	Mn	16,104	1.59	181	*118	7	94	96	214	18	92	0.810	282.6	0.9	3.8	87	6
208.	Mn	1162	0.13	274	*178	55	69	80	148	27	82	0.050	13.3	0	2.5	57	14
209.	Mn	1575	0.21	165	*107	14	87	92	149	14	91	0.036	9.4	0	5.8	133	20
210.	Mn	7536	0.39	218	*142	34	76	84	401	38	91	0.051	22.5	1.0	15.3	350	21
211.	Mi	35,176	6.20	108	75	24	68	78	93	18	81	0.23	60.0	0	13.5	310	32
212.	Mn	5661	0.60	204	*133	9	93	96	339	23	93	NR	NR	NR	NR	NR	NR
213.	Mn	15,341	2.40	169	*105	23	78	86	135	30	78	0.337	87.5	0.3	10.5	240	32
214.	Mn	2093	NR	201	*131	27	79	87	175	32	82	0.090	35.3	0.1	NR	NR	NR
215.	Pa		0.82	95	* 62	9	85	91	160	21	87	0.305	66.4	NR	3.7	62	6
216.	Mn	2425	0.21	348	*226	25	89	93	299	34	89	0.054	19.0	0	3.9	90	21
217.	Mn	4640	0.46	325	*211	24	89	93	208	65	69	0.121	37.0	0.8	13.9	320	22
218.	Mn	6789	0.67	190	*123	26	79	86	163	39	76	0.105	27.5	0.5	9.5	220	25
219.	Wis		9.93	144	95	14	85	90	155	23	85	2.88	782.7	0	3.4	78	10
220.	Mn	9825	1.62	478	*310	24	92	95	436	19	96	0.59	154.3		2.7	62	27

Mn..........Minnesota
Mi..........Michigan
Pa..........Pennsylvania
N.D........North Dakota
Wi..........Wisconsin

TABLE 1-C
REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS WITH CHEMICAL TREATMENT

Municipality	1970 Pop.	Sew. Flow	BOD$_5$					Susp. Solids			Filter Loading						Total P	
			Raw	PE	FE	% Rem.		Raw	FE	% Rem.	Area	Vol.	R	MGAD	Gals. per Day per sq.ft.	Lbs. BOD Per 1000 cu.ft.	FE	% Rem.
		MGD	mg/l	mg/l	mg/l	PE-FE	Raw FE	mg/l	mg/l	Raw-FE	Acres	1000 cu.ft.					mg/l	Raw FE
A. Rock Media																		
301. Mi	2457	0.64	175	61	21	66	80	188	26	86	0.172	44.5	0	3.7	85	7.3	1.0	86
302. Mi	9232	1.93	327	161	31	81	91	118	19	14	0.715	249.2	0	3.1	70	10.4	1.8	73
303. Mi	2618	0.43	84	48	14	71	83	92	19	79	0.29	76.0	3.2	6.9	160	2.3	1.2	80
304. Mi	35,176	7.30	103	61	16	74	84	132	16	88	0.46	120.0	0	15.8	360	30.8	1.1	12
305. Mi	2600	0.25	249	133	14	89	94	242	29	88	0.19	51.0	0	1.3	30	5.4	1.5	79
312. Mi	8940	1.58	147	70	21	73	86	137	19	86	0.13	39.6	NR	10.2	235	23.3		
306. Mi	4811	1.18	185	72	24	64	88	225	17	92	0.14	33.0	0.8	15.8	365	21.5	1.9	71
307. Mi	3094	0.65	190	44	12	73	94	175	28	84	0.11	29.4	1.0	11.6	265	8.1	0.7	91
308. Mi	9295	1.36	224	163	34	79	85	221	21	90	0.19	55.0	0	7.0	160	33.6	2.6	
Averages A plants			187	90	21	77	89	170	22	86								
B. Plastic Media																		
314. Mi	49,449	11.57	89	79	18	77	80	169	25	85	0.20	184.9	0.2	58.7	1350	41.3	1.0	85
310. Mi	NR	1.60	190	54	21	61	89	186	12	94	0.06	51.8	2.0	77.8	178.5	13.9	1.6	80
309. Mi	4980	0.94	75	23	11	52	85	99	11	89	0.02	15.0	1.0	116.0	2660	12.0	0.4	91
311. Mi	7493	1.15	111	62	15	76	83	102	12	88	0.04	37.7	0	27.5	630	15.8	0.9	90
313. Mi	3225	0.35	148	61	23	59	84	322	25	92	0.16	15.6	2.0	60.6	1390	18.0	2.0	80
Averages B plants			123	56	18	65	85	175	17	90								
Averages all plants			165	78	20	74	88	172	20	88								

FIG. 1
REMOVAL OF 5–DAY BOD
BY TRICKLING FILTER PLANTS – SINGLE STAGE
SHOWING RELATIONSHIP TO HYDRAULIC LOADING

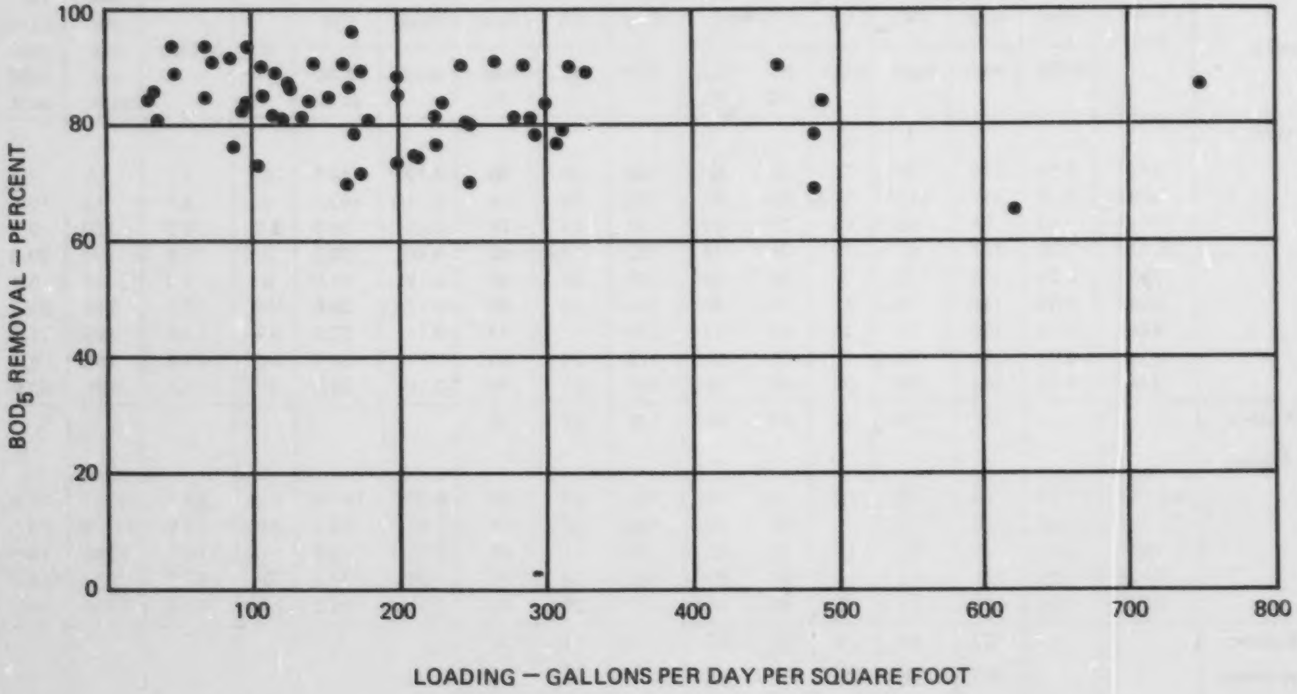


TABLE 2
EFFECT OF HYDRAULIC LOADING ON REMOVAL OF 5-DAY BOD BY TRICKLING FILTER PLANTS – SINGLE STAGE

Filter Loading		No. of Plants	BOD_5	Percent Removal	
Gals. per Day per sq.ft.			FE	PE to FE	Raw to FE
Range	Mean		mg/l		
0-99	62	11	25	80	87
100-199	142	21	37	76	85
200-299	242	17	36	71	82
300-399	314	5	34	75	84
400-499	478	4	36	64	75
500-599	–	–	–	–	–
600-699	620	1	38	49	66
700-799	744	1	37	81	87
>800	1630	1	37	69	80
Weighted Averages		61	36	73	83

FIG. 2
EFFECT OF RECIRCULATION
ON REMOVAL OF 5–DAY BOD

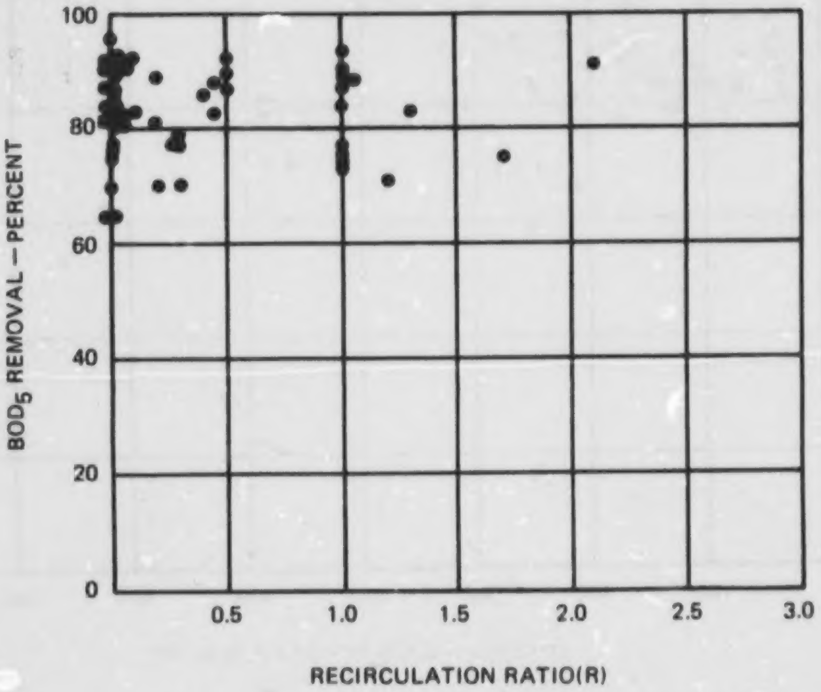


TABLE 3
EFFECT OF HYDRAULIC LOADING ON REMOVAL OF SUSPENDED SOLIDS BY TRICKLING FILTER PLANTS – SINGLE STAGE

Filter Loading		No. of Plants	SUSPENDED SOLIDS		Percent Removal
Gals. per Day per sq.ft.			RAW	FE	Raw to FE
Range	Mean		mg/l	mg/l	
0-99	70	11	171	27	84
100-199	140	20	218	32	85
200-299	239	16	173	32	80
300-399	314	5	261	25	90
400-499	478	4	148	38	75
500-599	–	–	–	–	–
600-699	620	1	93	58	63
700-799	744	1	293	45	85
>800	1630	1	193	47	76
Weighted Averages		59	195	32	84

FIG. 3
REMOVAL OF SUSPENDED SOLIDS BY TRICKLING FILTER PLANTS– SINGLE STAGE SHOWING RELATIONSHIP TO HYDRAULIC LOADING
60 PLANTS

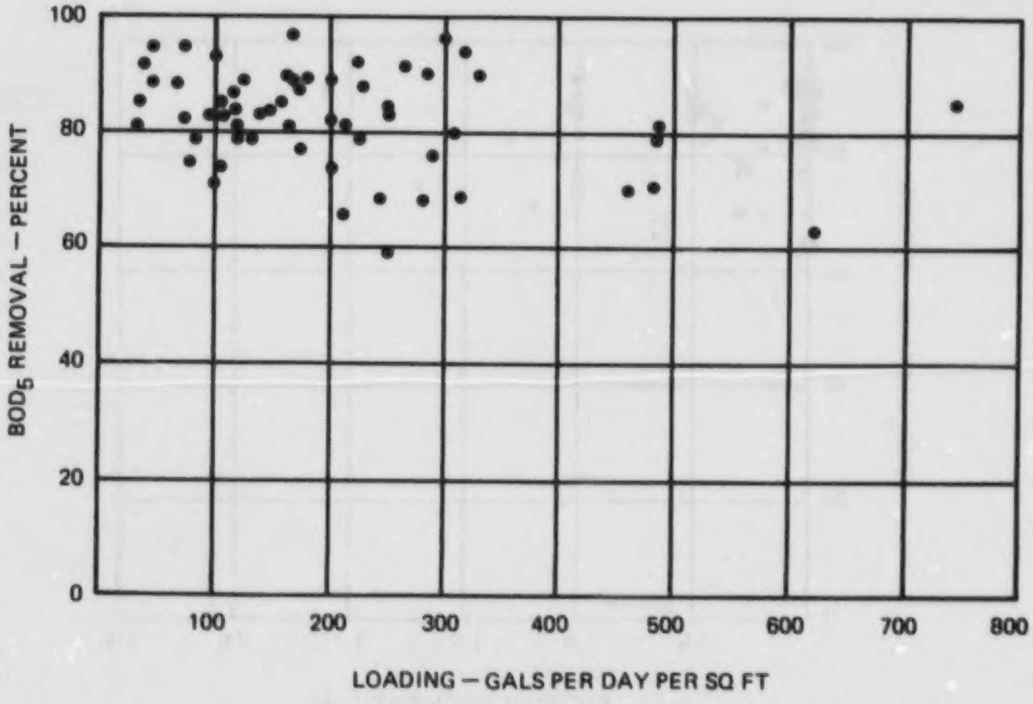


TABLE 4
EFFECT OF ORGANIC LOADING ON REMOVAL OF 5-DAY BOD BY TRICKLING FILTER PLANTS – SINGLE STAGE

Filter Loading		No. of Plants	BOD_5	Percent Removal	
Lbs. BOD_5 per 1000 cu.ft.			mg/l	PE to FE	Raw to FE
Range	Mean		FE		
0-20	11	20	27	73	81
21-40	28	23	38	74	82
41-60	50	10	40	75	85
61-80	69	4	38	68	78
81-100	–	–	–	–	–
101-120	106	2	63	76	83
121-140	124	2	32	80	87
Weighted Averages		61	36	73	83

FIG. 4
REMOVAL OF BOD_5
BY TRICKLING FILTER PLANTS
SINGLE STAGE
SHOWING RELATIONSHIP TO BOD LOADING
60 PLANTS

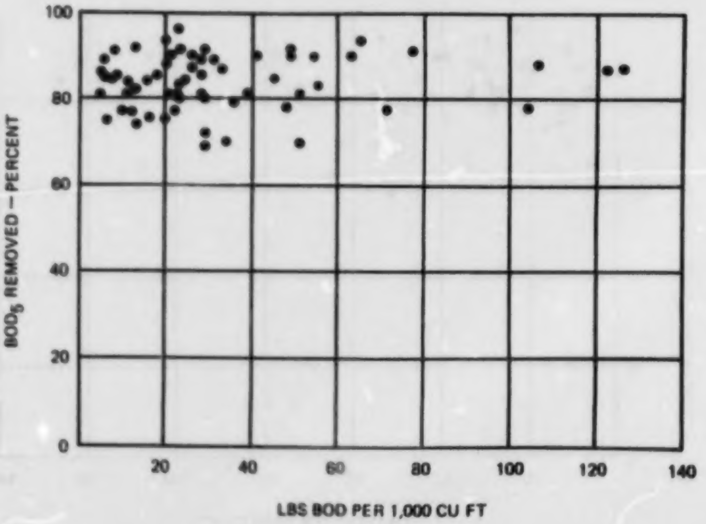


TABLE 5
EFFECT OF ORGANIC LOADING ON REMOVAL OF SUSPENDED SOLIDS BY TRICKLING FILTER PLANTS – SINGLE STAGE

Filter Loading		No.	SUSPENDED SOLIDS		Percent Removal
Lbs. BOD_5 per 1000 cu.ft.		of	FE	FE	Raw to
Range	Mean	Plants	mg/l	mg/l	FE
0-19	11	18	165	29	82
20-39	26	24	214	29	86
40-59	49	9	177	33	81
60-79	69	4	218	48	78
80-99	–	–	–	–	–
100-119	106	1	260	26	90
120-139	124	2	296	39	87
>140	275	1	193	47	76
Weighted Averages		59	198	32	84

FIG. 5
REMOVAL OF SUSPENDED SOLIDS
BY TRICKLING FILTER PLANTS – SINGLE STAGE
SHOWING RELATIONSHIP TO ORGANIC LOADING
60 PLANTS

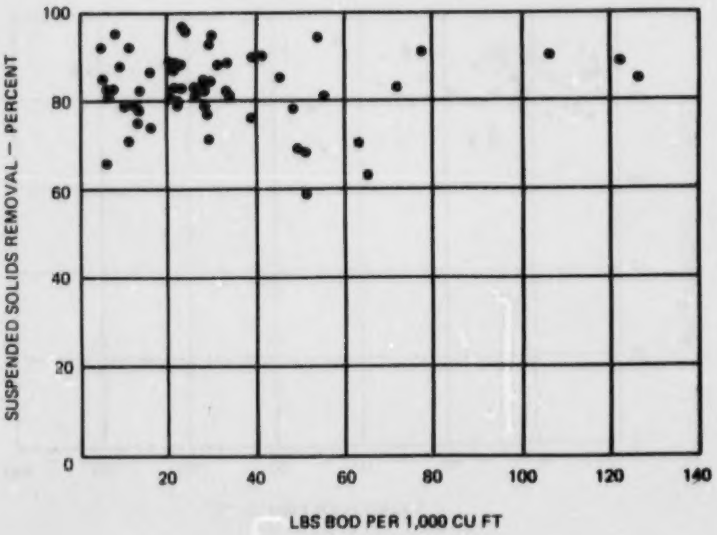


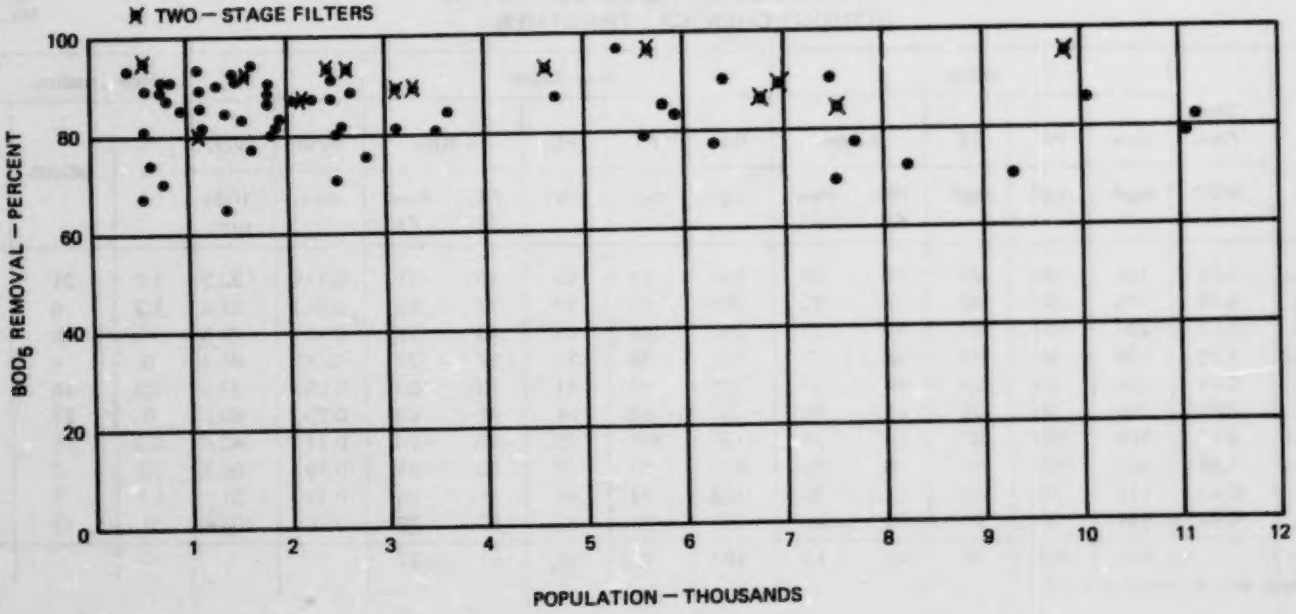
TABLE 6
REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS BY SINGLE-STAGE TRICKLING FILTERS WITHOUT CHEMICAL TREATMENT

Mn..........Minnesota
Mi...........Michigan
Pa...........Pennsylvania
N.D........North Dakota
Wi..........Wisconsin

Municipality	Sew. Flow	BOD$_5$					Susp. Solids					Filter Loading					
		Raw	PE	FE	% Rem.		Raw	PE	FE	% Rem.		Area	Vol.	R	MGAD	Gals. per Day per sq.ft.	Lbs. BOD per 1000 cu.ft.
	MGD	mg/l	mg/l	mg/l	PE-FE	Raw-FE	mg/l	mg/l	mg/l	PE-FE	Raw-FE	Acres	1000 cu.ft.				
101. Mi	1.07	134	99	42	58	69	139	91	41	55	71	0.115	30.2	1.2	21	480	29
102. Mi	0.40	195	151	33	78	83	183	96	22	77	88	0.093	21.8	1.3	6	137	23
103. Mi	0.77	224	119	63	47	72	256	104	59	43	77	0.10	26.5	NR	8	183	29
104. Mi	1.28	138	91	32	65	77	178	88	38	57	79	0.36	94.3	0	4	92	10
105. Mi	0.94	104	65	23	64	77	150	70	21	73	86	0.09	22.8	0.3	14	320	22
106. Mi	620	108	75	38	49	65	93	58	34	41	63	0.23	60.0	0	27	618	65
107. Mn	2.40	169	105	37	64	78	135	NR	30	NR	78	0.11	43.8	0.3	17	390	48
108. Mi	1.36	224	163	67	59	70	221	92	43	53	81	0.19	55.2	0.3	7	165	34
109. Mi	0.41	115	59	29	51	75	158	77	53	31	66	0.12	31.7	1.7	9	206	6
110. Wi	9.93	144	95	27	72	81	155	93	37	60	76	0.78	203.9	0	13	298	39
Averages		156	102	39	62	75	167	77	38	51	77						

*First stage only at two-stage plant.

FIG. 6
RELATIONSHIP OF POPULATION
TO
REMOVAL OF BOD



No apparent difference can be observed in plants with recirculation ratios of 1.0 or higher when compared with those with ratios of 0.2 or no recirculation at all.

It is indicated in Table 5 and Fig. 5 that suspended solids removal at all BOD loading ranges followed the BOD removal patterns very closely. No observed relationship to recirculation ratios is apparent.

Table 6 summarizes performance of 10 single-stage installations for which in-depth studies are included in the Appendix. These facilities were selected principally on the basis of the completeness of the process information and laboratory analyses and the rather wide range in size, quantity of flow and strength of wastes. In many respects these plants are very similar to those reported in Table 1 and are also included with that listing. On the whole, BOD and suspended solids removals for these 10 plants follow patterns similar to others in Table 1. The BOD of the effluent from these single-stage plants is quite comparable to the other plants. However, overall removal on the average is somewhat lower, influenced mainly by two of the 10 plants with effluents of 63 and 67 mg/l of BOD (72% and 70% removal respectively, based on raw wastes of 224 mg/l BOD at both plants). If these plants were excluded, values for the remaining eight would be 33 mg/l BOD in the effluent and 76% removal. On the same basis, suspended solids would be 35 mg/l in the effluent with 77% removal.

Relationship of Population to Removal of BOD

Data on BOD_5 removal vs. population are taken from Table 1 and plotted in Fig. 6. This information is summarized in Table 7.

TABLE 7

Population of Municipality	PERCENT REMOVAL BOD_5			
	Single-stage Filters		Two-stage Filters	
	# Plants	% Removal	# Plants	% Removal
1000	11	83	1	95
1000-1999	18	85	2	86
2000-2999	9	84	3	91
3000-3999	3	82	2	88
4000-4999	1	87	1	95
5000-5999	11	81	5	90
10000	8	78	4	88
Totals	61		18	

It is clearly indicated that trickling filter plants in very small communities are performing as effectively as those in the medium to large installations. It is noteworthy that this large sampling of plants, both single and two-stage, includes a great variety of facilities, ranges of loadings, waste compositions, flow patterns and operational methods.

Effects of Raw Wastewater Temperature on Plant Performance

Information on raw wastewater temperature and the concentration of BOD_5 and suspended solids in the plant effluent for the four winter months (January through April) is compared with corresponding information for four summer months (June through September) in Table 8.

The monthly averages indicated by these data for 22 plants are recorded in the Appendix. It is of interest to note that only two of the filter systems are enclosed in protective housings. Both have two-stage filters, one with rock media, one with plastic media. At most of the other installations, special steps are taken to prevent ice formation on the filter surfaces and to quickly remove ice as it forms in extremely cold weather. Recirculation rates are reduced in view of the fact that the sewage temperature drops sharply as the wastes pass through the filter and settling tanks. At one facility (301) where winter performance is about the same as summer, one filter and the final settling tank is taken out of service from mid-November to early April in order to minimize the temperature drop. Considerably better performance was experienced when this program was undertaken. An extreme case of temperature drop and its deleterious effect on plant performance is noted at another facility (112), where detention in the primary settling tanks averages 4 hours or more and final settling tanks average about 5 hours. With lower nighttime flows and colder temperatures, these detention times appear to inhibit biological activity and retard sedimentation in the final settling tanks.

Some plants have better physical protection from prevailing winds than others. These include locations with more favorable topography and natural wind breaks and erection of wind barriers such as baled hay or straw, snow fences, etc.

A fairly consistent temperature related trend in BOD removal, generally applicable to the majority of these plants, is found in these data at plants without chemical treatment. Seven of the nine plants had lower BOD_5 values in summer, with the nine plants averaging 69% of the winter values. These differences are not as great at plants with chemical treatments. In general, both groups have a somewhat lower BOD_5 in the effluent during the summer months, averaging about 72% of winter concentrations. However, suspended solids concentrations for the 22 plants remained constant for both groups in summer and winter.

Obviously, factors other than the air temperatures and raw wastewater temperature influence plant performance. The other factors probably mask to some extent the temperature effects, sometimes aggravating and sometimes offsetting their influence. A brief inspection of the month-by-month analytical data for these 22 plants reveals many variations in effluent quality which cannot be correlated with temperature variation. It seems apparent that the trickling filter process is not always seriously affected by the severe cold weather associated with winter sewage temperatures. This observation is confirmed by review of the 12-month records for plants in Minnesota, many in the northern part of the state, where winter air temperatures are often far below freezing for very long periods. Because of the severity of winters in most of Minnesota, it is customary to house the trickling filters to prevent ice formations on the filter surface, distributors and side walls. Overall performance in winter compared with rest of the year is generally similar to that observed at the 22 plants listed in Table 8.

Effect of Surface Overflow Rates in Final Settling Tanks

Information on sizes of final settling tanks and surface overflow rates at 23 plants is recorded in the Appendix. Surface overflow rates at annual average flows for these plants are summarized in Table 9. Values for BOD_5 and suspended solids of the final settling tank effluent and overall percent removals are indicated for the various plants (listed in order of increasing overflow rates). The plants are grouped as single-stage without chemical treatment, single-stage with chemical treatment and two-stage of which three have chemical treatment. Data are reported in the Appendix for three plants for periods both before and after chemical treatment was begun (plants 169, 162 and 171). Data at two of the plants (166 and 144), operated in a two-stage mode, are reported in group C as 219 and 213, respectively.

The range of loadings on the filters and final settling tanks is sufficiently wide to provide some indication of the effect of surface overflow rates on effluent quality and overall reduction of BOD_5 and suspended solids. An examination of the data, however, gives no apparent indication as to the critical point where performance levels decrease. In the single-stage group A without chemical treatment, no observable difference in performance is found in the total range reported (surface overflow rates from 250 to 1100 gpd/ft^2). Similarly, no observable difference is to be found in Group B, single-stage plants with chemical treatment where rates range from 290 to 1340 gpd/ft^2. Less variation apparently occurs among these nine plants than those without chemical treatment, possibly because of the leveling effect of the chemical treatment. This was also believed to be true of the five two-stage plants.

Effect of Sludge Handling Practices on Filter Performance

The customary variety of methods of treatment and disposal of sludge from the primary and final settling tanks are employed in the 25 plants studied. Eighteen of the plants have anaerobic digesters. All of the digesters are heated and 15 have two or more digestion tanks, most commonly operated in series. Supernatant at 17 of these plants is

TABLE 8
RELATIONSHIP OF RAW WASTEWATER TEMPERATURE TO REMOVAL OF BOD_5 AND SUSPENDED SOLIDS BY TRICKLING FILTER PLANTS IN COLD CLIMATES

Mn..........Minnesota
Mi...........Michigan
Pa...........Pennsylvania
N.D........North Dakota
Wi..........Wisconsin

Municipality	Winter			Summer			Summer % of Winter	
	Sew. Temp. °F	BOD_5 Mg/l	SS Mg/l	Sew. Temp. °F	BOD_5 Mg/l	SS Mg/l	BOD_5 Mg/l	SS Mg/l
A. WITHOUT CHEMICALS								
107. Mi	52	40	40	62	46	43	112	105
110. Mi	ND	38	26	ND	29	22	76	85
112. Mi	53	80	66	69	44	50	55	76
125. Mi	51	41	40	61	25	38	61	95
132. Mi	ND	26	21	ND	22	17	85	81
117. Mn	ND	41	37	ND	13	38	32	103
160. Mi	70	21	40	77	10	51	48	128
163. Mi	52	26	39	64	28	56	108	144
166. Wi	55	16	20	66	12	26	75	130
Averages A Plants		36	37		25	38	69	103
B. WITH CHEMICALS								
301. Mi	57	18	25	62	21	22	117	88
302. Mi	53	30	16	66	25	18	83	113
303. Mi	50	19	21	67	8	21	42	100
304. Mi	50	16	14	66	16	19	100	136
305. Mi	55	29	27	66	13	31	45	115
306. Mi	53	24	21	65	25	14	104	67
307. Mi	52	12	41	66	8	34	67	83
308. Mi	59	49	18	74	28	22	57	122
309. Mi	48	15	9	74	11	9	73	100
310. Mi	49	19	10	60	29	14	153	140
311. Mi	50	25	17	66	15	10	60	59
312. Mi	43	20	26	57	18	16	60	62
313. Mi	ND	22	18	ND	24	26	109	144
Averages B Plants		23	20		19	20	83	100
Averages All Plants		29	27		21	27	72	100

ND = No Data Winter: Jan-April Summer: June-Sept.

TABLE 9
RELATIONSHIP OF SURFACE OVERFLOW RATES TO REMOVAL OF BOD_5 AND SUSPENDED SOLIDS WITH AND WITHOUT CHEMICAL TREATMENT

Mn..........Minnesota
Mi...........Michigan
Wi..........Wisconsin

Municipality	Overflow Rate Gals./Day per Sq.Ft.	BOD_5 FE Mg/l	BOD_5 % Rem. Raw-FE	Susp. Solids FE Mg/l	Susp. Solids % Rem. Raw-FE
A. SINGLE-STAGE W/OUT CHEMICALS					
169. Mi	250	38	81	39	83
170. Mi	315	40	58	40	63
117. Mn	416	40	88	37	85
112. Mi	465	63	72	59	77
163. Mi	472	29	75	53	66
125. Mi	522	32	77	38	79
162. Mi	573	67	70	43	81
305. Mi	733	41	84	46	83
166. Wi	880	27	81	37	76
160. Mi	890	17	92	47	75
144. Mn	1100	37	78	30	78
*Intermediate Settling Tank					
B. SINGLE-STAGE WITH CHEMICALS					
302. Mi	290	31	91	19	84
301. Mi	470	21	88	26	86
310. Mi	503	21	89	12	85
313. Mi	530	23	84	25	92
308. Mi	573	34	85	21	90
314. Mi	630	18	80	25	85
307. Mi	675	12	94	28	84
305. Mi	833	14	94	29	88
309. Mi	1340	11	85	11	89
C. TWO-STAGE W/OUT CHEMICALS					
213. Mn	900	23	86	30	78
219. Wi	1028	14	90	23	85
D. TWO-STAGE WITH CHEMICALS					
306. Mi	260	24	88	17	92
312. Mi	277	21	86	24	86
311. Mi	560	15	83	12	88
**Two-Stages					

discharged to mix with the raw sewage before it reaches the primary settling tanks. At one plant, the supernatant is discharged to a sludge lagoon. Digestion tank capacities range from about 20-80 ft^3/lb of volatile solids added per day. Various methods and equipment are used for mixing the contents of the primary digesters. The secondary digesters are usually operated in a quiescent state without mixing. Of the plants without digesters, two use Imhoff tanks for sludge digestion and primary sedimentation. One plant uses Imhoff tanks solely for primary digestion of sludge with a heated digester used as the secondary. No supernatant or other digested sludge end product from these plants is returned to the plant flow. Two plants use lime for treatment of raw sludge with no end product returned to the plant flow. One large plant dewaters raw sludge after storage by means of vacuum filtration followed by incineration. The filtrate and the decant from the sludge storage tank are returned to the raw wastewater flow. One plant uses a wet combustion process followed by vacuum filtration, with land disposal of the filter cake. The filtrate and residue from the wet combustion process are returned to the raw sewage flow. One plant has land disposal. Digested sludges from digesters and Imhoff tanks are discharged to open drying beds except where filtered.

Capacities of sludge digestion tanks are shown on the data sheets in the Appendix under "Capacities and Loadings." Points of discharge of digested sludge, supernatant or other end products are stated and shown graphically in the flow pattern diagrams.

Although no observable relationship is apparent from a comparison of digester loadings and plant performance, operators at all of the plants are acutely conscious of the deleterious effect of shock loadings of "strong" supernatant on plant effluent quality. No other single problem commands as much attention as the continuous maintenance of effective digestion of sludge in order to produce a supernatant low in volatile acids, BOD and suspended solids. Customarily, supernantant is returned to the plant flow at very low rates during period of low diurnal sewage flow.

UPGRADING WITH A SECOND-STAGE FILTER

Studies were made on 20 filter plants where the filters are operated in series. Each of these plants have an intermediate settling tank or tanks following the first stage filter. In all other respects, the plant facilities are similar to those equipped with single-stage filters.

Hydraulic Filter Loading Rates

Data from Table 1, Part B are summarized in Tables 10 and 12 and plotted in Fig. 7. No apparent trends in relationships between hydraulic loading and BOD_5 or suspended solids removal are visually detectable. Loadings are similar in magnitude to those tabulated for the single-stage filter plants. No observable relationship is apparent between recirculation ratios and removal of BOD or suspended solids.

Organic Filter Loading Rates

Tables 11 and 13 and Fig. 8 exhibit a high degree of consistency in removal of BOD and suspended solids throughout the entire range of organic loadings, which are well distributed up to 40 lbs/1000 ft^3. One plant has a rate greater than 40 lbs/1000 ft^3. Here, as in the single-stage plants, no observable relationship is apparent between recirculation ratios and removal of BOD and suspended solids.

Comparison: Single-Stage vs. Two-Stage

Information on the 68 single-stage and 20 two-stage filter plants, all without chemical treatment, is summarized in the foregoing tables 1-13. These data provide a good basis for predicting levels of performance of single (or parallel) filter systems compared with two-stage (series) operations. Further comparisons are provided in Tables 14 and 15 and in the statistical probability plots presented in Figs. 9 and 10. These plots show a normal distribution of BOD values in both single and two-stage systems with a definite statistically significant difference in performance of the two systems. The probable value for the single-stage system is 83% removal compared with 89-90% for two-stage. It may be further noted that there is 90% probability that BOD removals will be 74% or higher for single-stage systems and 82% or higher for two-stage systems. The probability curve for removal of suspended solids at single-stage plants is visually identical with the BOD curve, although eight of the 54 values plotted fall below the line of best fit. Furthermore, there is no statistically significant difference in removal of suspended solids at single-stage and two-stage plants. No signficiant difference was observed at the 90% probability level with a spread of 85% to 87.5% removal at the most probable (50%) value.

TABLE 10
EFFECT OF HYDRAULIC LOADING ON REMOVAL OF 5-DAY BOD BY TRICKLING FILTER PLANTS – TWO STAGE

Filter Loading		No. of Plants	BOD_5	Percent Removal	
Gals. per Day per Sq.Ft.			FE	PE to FE	Raw to FE
Range	Mean		Mg/l		
0-99	70	7	26	85	90
100-199	120	2	27	90	93
200-299	236	6	23	83	89
300-399	326	3	27	78	85
Weighted Averages		18	25	83	89

TABLE 12
EFFECT OF HYDRAULIC LOADING ON REMOVAL OF SUSPENDED SOLIDS BY TRICKLING FILTER PLANTS – TWO STAGE

Filter Loading		No. of Plants	Suspended Solids		
Gals. per Day per Sq.Ft.			Raw	FE	% Rem.
Range	Mean		Mg/l	Mg/l	Raw-FE
0-99	73	7	232	28	87
100-199	120	2	345	28	92
200-299	236	6	188	30	83
300-399	327	3	234	40	80
400-499 & >		0	–	–	–
Weighted Averages		18	246	31	85

TABLE 11
EFFECT OF ORGANIC LOADING ON REMOVAL OF 5-DAY BOD BY TRICKLING FILTER PLANTS – TWO STAGE

Filter Loading		No. of Plants	BOD_5	Percent Removal	
Lbs. BOD per 1000 Cu.Ft.			FE	PE to FE	Raw to FE
Range	Mean		Mg/l		
0-20	9	6	21	85	90
21-40	27	11	26	82	88
41-60	–	0	–	–	–
61-80	74	1	40	92	95
Weighted Averages		18	25	84	89

TABLE 13
EFFECT OF ORGANIC LOADING ON REMOVAL OF SUSPENDED SOLIDS BY TRICKLING FILTER PLANTS – TWO STAGE

Filter Loading		No. of Plants	Suspended Solids		
Lbs. per 1000 Cu.Ft.			Raw	FE	% Rem.
Range	Mean		Mg/l	Mg/l	Raw-FE
0-19	9	6	165	22	86
20-39	28	11	241	35	84
40-59	--	0	–	–	–
60-79	74	1	541	42	92
Weighted Averages		18	232	31	85

FIG. 7
REMOVAL OF BOD$_5$
BY TRICKLING FILTER PLANTS
TWO–STAGE
SHOWING RELATIONSHIP TO HYDRAULIC LOADING
18 PLANTS

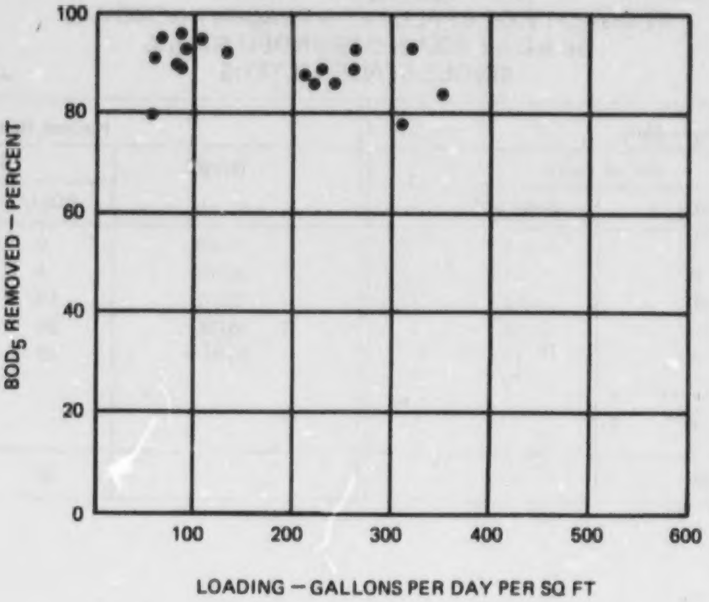


FIG. 8
REMOVAL OF BOD$_5$
BY TRICKLING FILTER PLANTS
TWO–STAGE
SHOWING RELATIONSHIP TO BOD LOADING

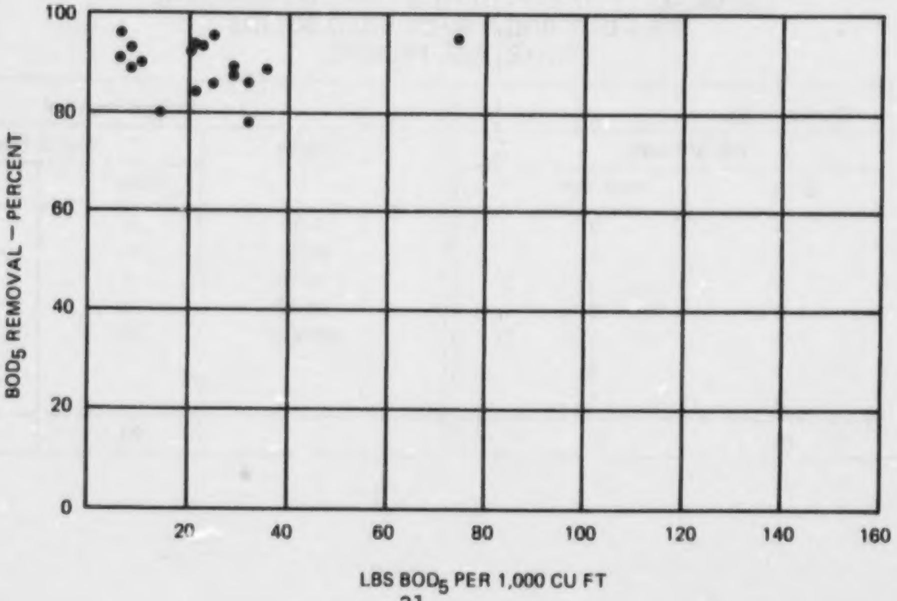


TABLE 14
DISTRIBUTION OF VALUES IN QUALITY OF EFFLUENT & PERCENT REMOVAL OF 5-DAY BOD & SUSPENDED SOLIDS
SINGLE-STAGE FILTERS

Quality ~ Mg/l			Percent Removal		
Range	No. of Plants		Range	No. of Plants	
	BOD$_5$	Susp. Sol.		BOD$_5$	Susp. Sol.
< 10	1	1	< 60	0	2
10-19	6	11	60-69	4	5
20-29	25	17	70-79	13	14
30-39	14	14	80-89	35	33
40-49	9	13	90 or >	16	12
50-59	7	7			
60-69	3	3			
70 or >	3				
Totals	68	66		68	66

TABLE 15
DISTRIBUTION OF VALUES IN QUALITY OF EFFLUENT & PERCENT REMOVAL OF 5-DAY BOD & SUSPENDED SOLIDS
TWO-STAGE FILTERS

Quality ~ Mg/l			Percent Removal		
Range	No. of Plants		Range	No. of Plants	
	BOD$_5$	Susp. Sol.		BOD$_5$	Susp. Sol.
< 10	4	0	< 60	0	0
10-19	2	6	60-69	0	1
20-29	9	5	70-79	1	4
30-39	2	5	80-89	9	7
40-49	2	1	90 or >	10	8
50-59	1	2			
60-79	0	1			
Totals	20	20		20	20

FIG. 9
COMPARISON OF
SINGLE STAGE VS TWO STAGE
TRICKLING FILTER PLANTS
IN REMOVAL OF BOD_5
76 PLANTS

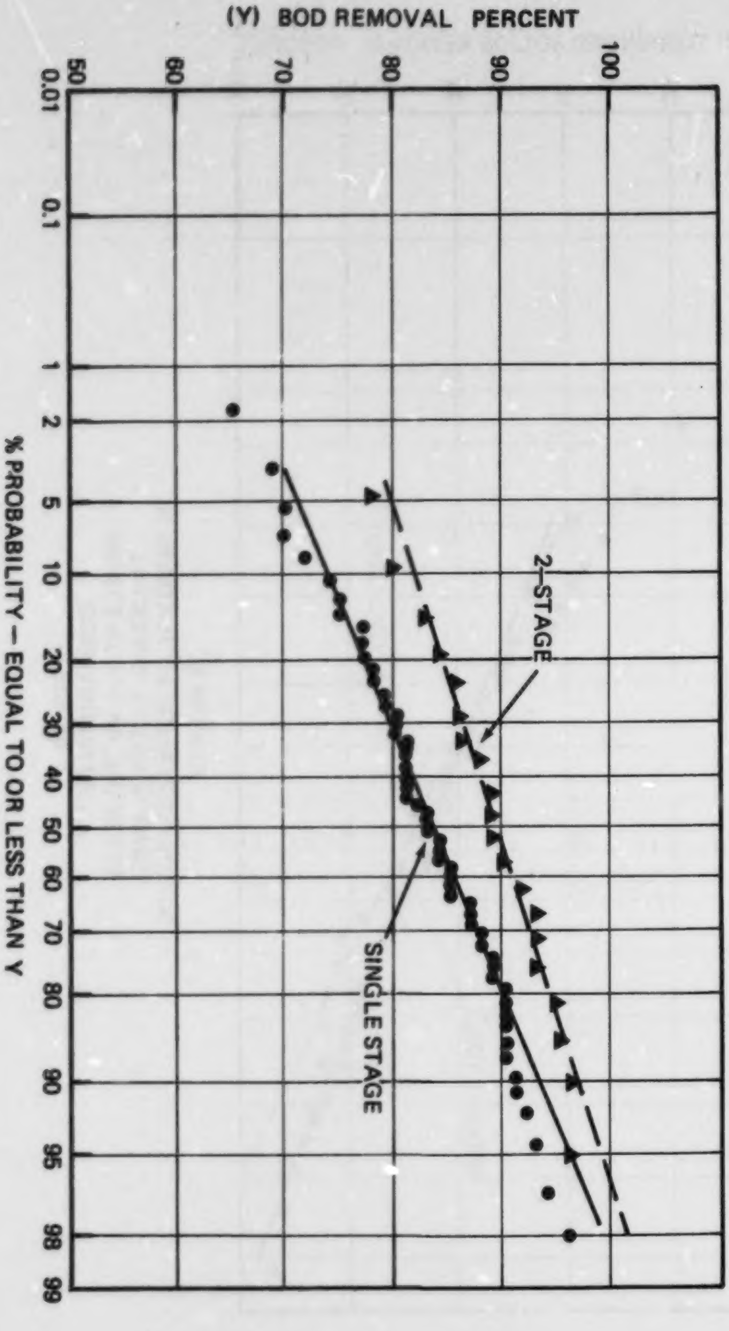


FIG. 10
COMPARISON OF
SINGLE STAGE VS TWO STAGE
TRICKLING FILTER PLANTS
IN REMOVAL OF SUSPENDED SOLIDS
74 PLANTS

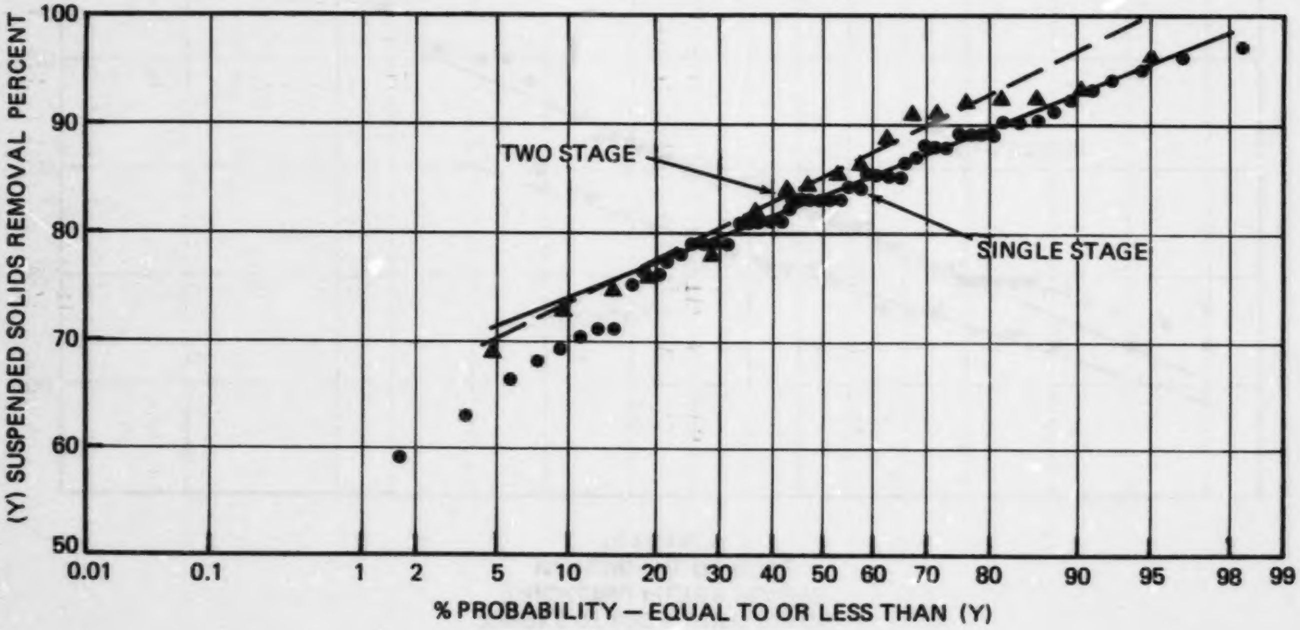


TABLE 16
COMPARISON OF BOD$_5$ REMOVAL BY SINGLE-STAGE VS TWO-STAGES AT 3 TYPICAL TWO-STAGE PLANTS

Mn..........Minnesota
Mi...........Michigan
Pa...........Pennsylvania
N.D........North Dakota
Wi.........Wisconsin

Municipality	BOD$_5$ ~ Mg/l				BOD$_5$ Removal ~ %				
	Raw	PE	IE	FE	PE-IE	Raw-IE	PE-FE	IE-FE	Raw-FE
211. Mi	108	75	38	24	50	65	76	42	78
213. Mn	169	105	37	23	64	78	78	38	86
219. Wi	144	95	27	14	72	81	85	48	90
Averages	140	92	34	20	63	76	78	42	85

IE = Intermediate Settling Tank Effluent

TABLE 17
COMPARISON OF BOD$_5$ REMOVAL BY SINGLE-STAGE VS TWO-STAGES ALL PLANTS

Stages	No. of Plants	BOD$_5$ ~ Mg/l			% Removal	
		Raw	Effluent		First Stage	Two Stages
			First Stage	Two Stages		
All Plants						
Single-Stage	68	226	35	NA	84	NA
Two-Stage	20	255	NR	24	NA	90
In-Depth Studies						
Single-Stage	10	156	39	NA	75	NA
Two-Stage	3	140	34	20	76	85

Some additional insight to the comparative level of performance of single and two-stage systems is provided by the in-depth design and performance data set forth in the Appendix for ten single-stage and three two-stage plants. Laboratory analyses for these three plants include information on the BOD_5 of the effluent of the settling tank following the first stage filter as well as the final settling tank effluent. This information is shown in Table 16. Data from Table 16 are included in Table 17 showing the numerical distribution of the effluent BOD by treatment process for single vs. two-stage filter systems.

Observations and Conclusions

Several observations may now be made from the summarized data and related discussions:

1. Effluent from final settling tanks following single-stage filters may be expected to vary considerably. In the plants studied effluent BOD_5 valus normally range from 10 to 50 mg/l with removals from the raw wastewater of 60 to 90% or more. Most probable values of the plant effluent are 36 mg/l BOD_5 and 83% removal. There is a 90% probability that overall BOD_5 removal will be 74% or higher.

2. Removal of BOD_5 at the 20 two-stage trickling filter plants studied appears to substantially higher than at single-stage systems. Removals of 80-90% are commonly experienced, the most probable value being 89-90% or higher. Thre is a 90% probability that removals will not be less than 82%.

3. Suspended solids in the effluent from 66 single-stage systems studied were at approximately the same concentration as the BOD_5 and percent removals followed precisely the same probability, distribution and magnitude.

4. Removal of suspended solids in the two-stage plants was not statistically significantly different from that observed in single-stage systems. The apparent indication is that generally no further removal of suspended solids can be expected by converting single-stage to two-stage operation.

5. Removal of BOD_5 and suspended solids at both single-stage and two-stage filter plants appeared to be relatively independent of the magnitude of both hydraulic and organic loadings within the loading limits of 68 single-stage and 20 two-stage systems studied. Hydraulic loadings varied from 100-320 gpd/ft^2 (5-15 MGAD) for single-stage and slightly higher for two-stage. A few values were considerably higher. Five-day BOD loadings were usually in the 10-60 lbs/1000 ft^3 range for both systems with a few values much higher.

6. No observable relationship was apparent between recirculated flow ratios and removal of BOD_5 or suspended solids. Plants with no or very low recirculation appeared to perform as well as these with recirculation ratios of 1 to 3 times the raw wastewater flow. This is not to imply that recirculation has no value. However, no effect was visually apparent from these data.

7. Both single-stage and two-stage plants presently operated at low to moderate hydraulic and organic loadings can be expected to accomodate much higher loadings without depreciation of effluent quality. For example: at a single-stage filter loaded at 15 lbs BOD_5/1000 ft^3 and 200 gpd/ft^2 of media, both hydraulic and organic loadings can be doubled without lowering the effluent quality.

8. Conversion of a single-stage system to two-stage can be expected to greatly improve the quality of effluent, with the same quantity of media. For example, assume two trickling filters operated in parallel with BOD_5 loadings at 15 lbs/1000 ft^3 and hydraulic loading of 300 gpd/ft^2 are producing a final settling tank effluent of 35-40 mg/l BOD_5. If these filters were arranged in series with an intermediate settling tank and low lift pumps, the plant effluent can be expected to be in the 25 mg/l range.

9. The converted plant in No. 8 above can be expected to reliably produce an effluent BOD_5 of 30 mg/l or less with about 90% removal compared to the raw sewage, even if this loading is doubled.

UPGRADING WITH CHEMICAL TREATMENT

In-depth studies were made at 14 trickling filter plants in Michigan where chemicals are added to remove phosphorus pursuant to a regional requirement for reduction of phosphorus loadings in the Great Lakes. A minimum of 80% removal is required. Plants selected have been adding chemicals for this purpose for over two years. All plants have typical facilities and the operational procedures are representative for the plant processes involved in this study. Excellent physical and laboratory data are routinely maintained and were made available for this study. Pertinent design information and performance data for the facilities are set forth in the Appendix. Flow diagrams are developed for each plant with points of application of the chemicals. Information includes kinds of chemicals and feed rates. A year or more of flow and analytical data for BOD_5 and suspended solids and, where available, total phosphorus, provide a good indication of performance provided by the primary settling tanks and filter systems. Summary data are developed from this information for analysis and discussion in this report.

Facilities for Chemical Treatment

Facilities are representative of those customarily used for removal of phosphorus by precipitation and removal of a high proportion of colloids by flocculation or agglomeration. In some of these plants chemical treatment was undertaken after the plant had been in operation for some time; in others it commenced when the plant was built.

Generally, facilities are simple and inexpensive with maximum use of hydraulic properties of the regular facilities to achieve the desired reactions.

Commonly, facilities consist of the following items for storage and application of the metal salts: a double-lined storage tank of 5,000-6,000 gallon capacity, 2 diaphragm pumps paced off the flow meter and a ½" to 1" plastic pipe feed line. These facilities are usually located in the pump room with provision for total containment of spills or leaks. Points of application are ahead of a comminutor, Parshall flume or aerated grit chamber to provide rapid and thorough mixing of the metal salt with the raw wastes entering the plant. A polymer is introduced in small quantities to the raw wastes following the comminutor, parshall flume or aerated grit chamber with 5-10 minutes contact time in the well-mixed flow before entering the primary settling tank.

Chemicals Used

Of the 14 plants studied, 11 use ferric chloride and an anionic polymer. Feed rates for most plants range from 25-40 mg/l as $FeCl_3$. Polymer dosage is usually from 0.1-0.3 mg/l.

At one plant, aluminum chloride ($AlCl_3$) is added to the trickling filter effluent ahead of an aerated mixing chamber with about 10 minutes detention time at average sewage flow rates. Chemical dosages average about 38 mg/l as $AlCl_3$. The $AlCl_3$ is fed in 25% solution. The polymer is introduced in the line between the mixing chamber and the final settling tanks.

One plant uses lime, applied at the flocculator - clarifier for the dual purpose of phosphorus removal and sludge treatment. Feed rates average 2,400 lbs/day as CaO, dry weight, for an average flow of 1.36 MGD (approximately 210 mg/l). Another plant feeds hydrated lime with 1.5 minutes rapid mix followed by 15 minutes aerated flocculation in primary clarifier.

Phosphorus Removal

Phosphorus in the raw wastes entering the plant is usually in the 6-8 mg/l range. Chemical treatment reduces the phosphorus concentration to 1-2 mg/l with some below this range. At the plant feeding lime after filtration phosphorus averages about 2.6 mg/l.

Removal of BOD_5 and Suspended Solids

Data are summarized in Table 18 from the physical and analytical information recorded on sheets entitled "Facilities and Loadings" in the Appendix.

Eleven of the plants are operated as single-stage. Two rock media systems and one plastic media filter system are two-stage. It is noteworthy that five of the 14 plants have plastic media in 21ft-22ft towers. The other nine use rock media, eight at customary depths of 6 ft. and one at 8 ft. This provides an excellent opportunity for comparison of performance at various loadings. Five of the rock media filter plants and one of the plants with plastic media have reliable data for a significant period of time before chemical additions were made. This provides an excellent basis for comparison of performance with and without chemical treatment as here practiced (see Table 19).

It is noted from Table 18 (also Table 1C) that the hydraulic and organic loadings on all rock media filter systems are typical of those listed in Table 1 and previously discussed. Hydraulic loadings per unit area are, of course, higher on the plastic media systems with comparatively less surface area, but are comparable to the rock filters on a media volume basis. Organic loadings are comparable at the rock and plastic media systems in Table 18 and in the same general range as the 86 plants listed in Table 1A and 1B.

Strength of the raw wastewaters, as measured by BOD_5 and suspended solids, is slightly higher at the rock media plants than the plastic media plants but generally comparable to those in Table 1A and 1B.

Mn.........Minnesota
Mi..........Michigan
Pa...........Pennsylvania
N.D.......North Dakota
Wi.........Wisconsin

TABLE 18
REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS WITH CHEMICAL TREATMENT

Municipality	1970 Pop.	Sew. Flow	BOD$_5$					Susp. Solids			Filter Loading						Total P	
			Raw	PE	FE	% Rem.		Raw	FE	% Rem.	Area	Vol.	R	MGAD	Gals. per Day per sq.ft.	Lbs. BOD Per 1000 cu.ft.	FE	% Rem.
		MGD	mg/l	mg/l	mg/l	PE-FE	Raw FE	mg/l	mg/l	Raw-FE	Acres	1000 cu.ft.					mg/l	Raw FE
A. Rock Media																		
301. Mi	2457	0.64	175	61	21	66	80	188	26	86	0.172	44.5	0	3.7	85	7.3	1.0	86
302. Mi	9232	1.93	327	161	31	81	91	118	19	14	0.715	249.2	0	3.1	70	10.4	1.8	73
303. Mi	2618	0.43	84	48	14	71	83	92	19	79	0.29	76.0	3.2	6.9	160	2.3	1.2	80
304. Mi	35,176	7.30	103	61	16	74	84	132	16	88	0.46	120.0	0	15.8	360	30.8	1.1	12
305. Mi	2600	0.25	249	133	14	89	94	242	29	88	0.19	51.0	0	1.3	30	5.4	1.5	79
312. Mi	8940	1.58	147	70	21	73	86	137	19	86	0.13	39.6	NR	10.2	235	23.3		
306. Mi	4811	1.18	185	72	24	64	88	225	17	92	0.14	33.0	0.8	15.8	365	21.5	1.9	71
307. Mi	3094	0.65	190	44	12	73	94	175	28	84	0.11	29.4	1.0	11.6	265	8.1	0.7	91
308. Mi	9295	1.36	224	163	34	79	85	221	21	90	0.19	55.0	0	7.0	160	33.6	2.6	
Averages A plants			187	90	21	77	89	170	22	86								
B. Plastic Media																		
314. Mi	49,449	11.57	89	79	18	77	80	169	25	85	0.20	184.9	0.2	58.7	1350	41.3	1.0	85
310. Mi	NR	1.60	190	54	21	61	89	186	12	94	0.06	51.8	2.0	77.8	178.5	13.9	1.6	80
309. Mi	4980	0.94	75	23	11	52	85	99	11	89	0.02	15.0	1.0	116.0	2660	12.0	0.4	91
311. Mi	7493	1.15	111	62	15	76	83	102	12	88	0.04	37.7	0	27.5	630	15.8	0.9	90
313. Mi	3225	0.35	148	61	23	59	84	322	25	92	0.16	15.6	2.0	60.6	1390	18.0	2.0	80
Averages B plants			123	56	18	65	85	175	17	90								
Averages all plants			165	78	20	74	88	172	20	88								

Removal of BOD in the primary settling tank of most of these plants, where chemicals are added to the raw wastewaters, is generally very high. This is clearly illustrated in Table 19, which summarizes performance data at the six plants for which information is available before and after chemical precipitation was commenced. Five-day BOD and suspended solids removals at the 5 plants with chemicals added before primary sedimentation were 57% and 76% respectively compared with 31% and 55% for a period of several months before chemical treatment. In other words, approximately 50% more BOD and suspended solids were removed by primary sedimentation with chemical treatment in this manner.

A broader base of comparison is provided in Table 20 which summarizes BOD_5 and suspended solids concentrations in the raw wastewater and primary settling tank effluent at all 23 plants where in-depth studies were made. Data are summarized from 16 plants without chemical additions and 13 plants with chemical additions. The six plants in Table 19 are included here in both categories. The higher percent removal for the 13 plants in Table 20 with chemical treatment is in the same order of magnitude as for the six plants listed in Table 19.

The marked improvement in effluent quality provided by chemical treatment at single-stage filter plants is shown in Table 21. Both effluent BOD_5 and suspended solids concentrations were reduced approximately one-half. It is noteworthy also that effluent quality at the 14 plants with chemical treatment, as measured by suspended solids, is substantially better than observed at the 18 two-stage filter plants without chemicals summarized in Table 18 although BOD_5 values are very similar. These relationships are portrayed graphically in the probability plots (Figs. 11, 12, and 13).

Relationship Between Filter Media and Performance

As may be noted from Tables 18 and 21, overall performance at the five plastic media filters is very similar to that experienced at the nine rock media filters. No apparent difference is found in performance of the only two-stage plastic media filter compared with the single-stage filters on the basis of the data gathered for this report.

Relationship Between Recirculation and Performance

Recirculation ratios at rock media filters listed in Table 18 vary from zero at five plants to 0.8, 1.0 and 3.2 at the other three for which this information is available. No apparent effect of recirculation on plant performance, as measured by removal of BOD_5 and suspended solids, were observed in these data.

Recirculation is a common operational practice used for deep plastic media filters - an inherent characteristic of the process. Very little recirculation is used, however, at one plant (314) where the raw wastes are very dilute because of the combined sewer system. On the other hand, at another plant (309) with a combined sewer system and very dilute waste, a recirculation ratio of 1.0 is used. Removals at plant

Mn..........Minnesota
Mi..........Michigan
Pa..........Pennsylvania
N.D........North Dakota
Wi..........Wisconsin

TABLE 19
COMPARISON OF
BOD AND SUSPENDED SOLIDS REMOVAL
BEFORE AND AFTER CHEMICAL ADDITIONS FOR REMOVAL OF PHOSPHORUS

Municipality	A or B	Sewage Flow	BOD$_5$						Suspended Solids						Total P	
			Raw	PE	FE	% Removal			Raw	PE	FE	% Removal			FE	% Rem.
		MGD	Mg/l	Mg/l	Mg/l	Raw-PE	PE-FE	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-PE	PE-FE	Raw-FE	Mg/l	Raw-FE
310. Mi	B	0.83	196	104	38	47	63	81	231	101	39	56	61	83	3.7	57
310. Mi	A	1.60	190	54	21	72	61	90	186	35	12	81	66	94	1.6	80
303. Mi	B		114	93	41	18	56	64	117	60	33	49	45	72	No Data	
303. Mi	A	0.43	84	48	14	43	71	83	92	51	19	45	63	79	1.2	80
304. Mi	B	6.2	108	75	24	31	68	78	93	58	18	38	69	81	5.0	14
304. Mi	A	7.3	103	61	16	41	74	84	132	42	16	68	62	88	1.1	82
305. Mi	B	0.22	254	191	41	25	79	84	263	122	46	54	62	83	8.7	26
305. Mi	A	0.25	249	133	14	47	89	94	242	52	29	79	44	88	1.5	79
306. Mi	B	1.2	193	121	56	37	54	71	224	85	36	62	58	84	No Data	
306. Mi	A	1.2	175	67	25	62	63	86	229	46	17	80	63	93	2.4	71
308. Mi	B	1.4	224	163	67	27	59	70	221	92	43	58	53	81	No Data	
308. Mi	A	1.4	224	*163	34	*	79	85	221	*92	21	*	77	90	2.6	
Averages	B	–	181	125	45	31	63	75	192	86	36	55	58	81		
Averages	A	–	171	73	21	57	73	87	184	45	19	76	60	89		

* Not included in averages. Chemicals added after trickling filter and its clarifier.

B = Before Chemical Treatment

A = After Chemical Treatment

TABLE 20
COMPARISON OF
REMOVALS OF BOD$_5$ AND SUSPENDED SOLIDS IN PRIMARY SEDIMENTATION TANKS WITH VS WITHOUT CHEMICAL TREATMENT

Mn..........Minnesota
Mi...........Michigan
Pa...........Pennsylvania
N.D........North Dakota
Wi..........Wisconsin

Municipality	BOD$_5$			Susp. Solids		
	Raw	PE	% Rem.	Raw	PE	% Rem.
	Mg/l	Mg/l	Raw-PE	Mg/l	Mg/l	Raw-PE
A. *WITHOUT CHEMICALS*						
107. Mi	134	99	26	139	91	35
110. Mi	195	151	22	183	96	48
112. Mi	224	119	51	256	104	59
125. Mi	138	91	34	178	88	51
132. Mi	104	65	38	150	70	53
144. Mn	169	105	38	ND	ND	
169. Mi	96	64	33	ND	ND	
160. Mi	219	153	30	187	93	50
163. Mi	115	59	49	158	77	51
166. Wi	144	95	34	155	93	40
Averages 10 Plants A	154	100	35	176	89	49
Averages 6 Plants, Table 19	181	125	31	192	86	55
Weighted Averages—16 Plants	164	109	34	182	88	51
B. *WITH CHEMICALS*						
301. Mi	175	61	65	188	65	65
302. Mi	327	161	51	118	76	36
309. Mi	75	23	69	99	18	82
311. Mi	121	56	54	107	39	64
312. Mi	147	70	52	137	62	55
313. Mi	148	61	59	322	50	84
307. Mi	190	44	77	175	65	64
Averages 7 Plants B	169	68	60	164	54	66
Averages 6 Plants, Table 19	171	73	57	184	45	76
Weighted Averages 13 Plants	170	70	59	174	50	71

FIG. 11
REMOVAL OF 5–DAY BOD
BY TRICKLING FILTER PLANTS
WITH VS WITHOUT CHEMICAL TREATMENT
SINGLE–STAGE ONLY

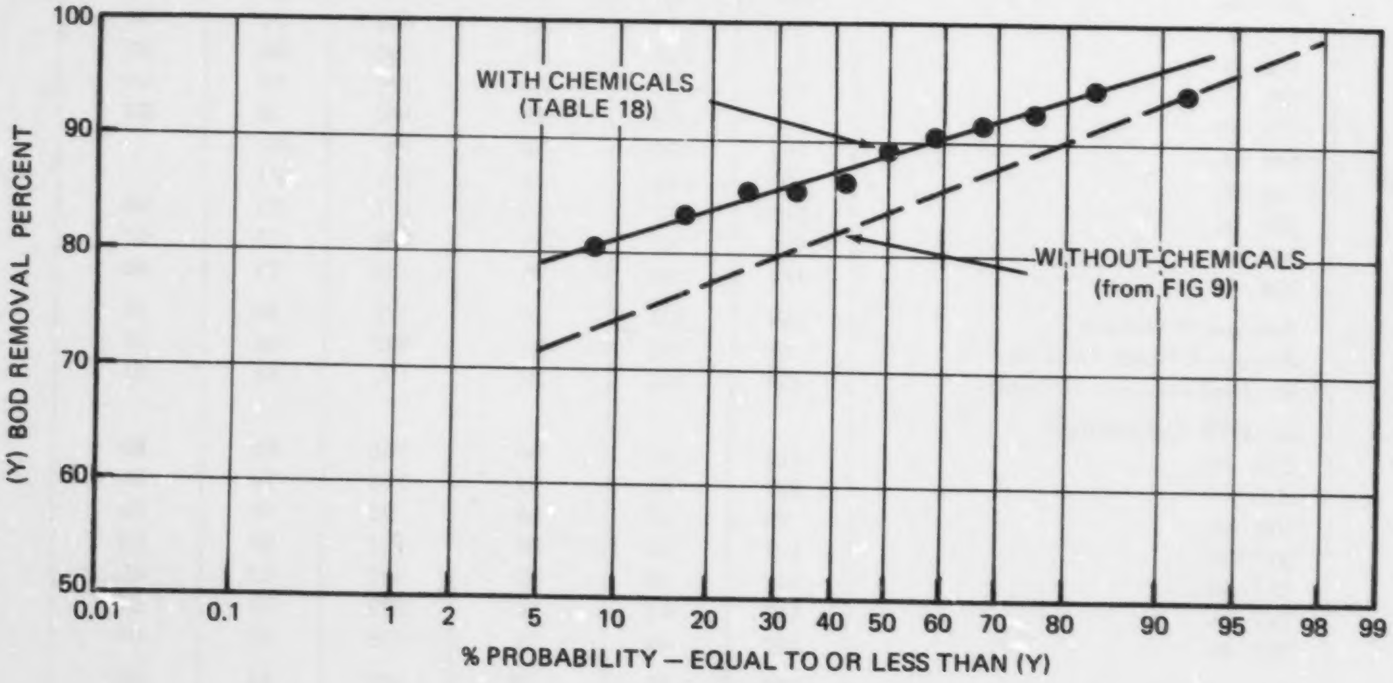


FIG. 12
REMOVAL OF SUSPENDED SOLIDS
BY TRICKLING FILTER PLANTS– SINGLE STAGE
WITH VS WITHOUT CHEMICAL TREATMENT

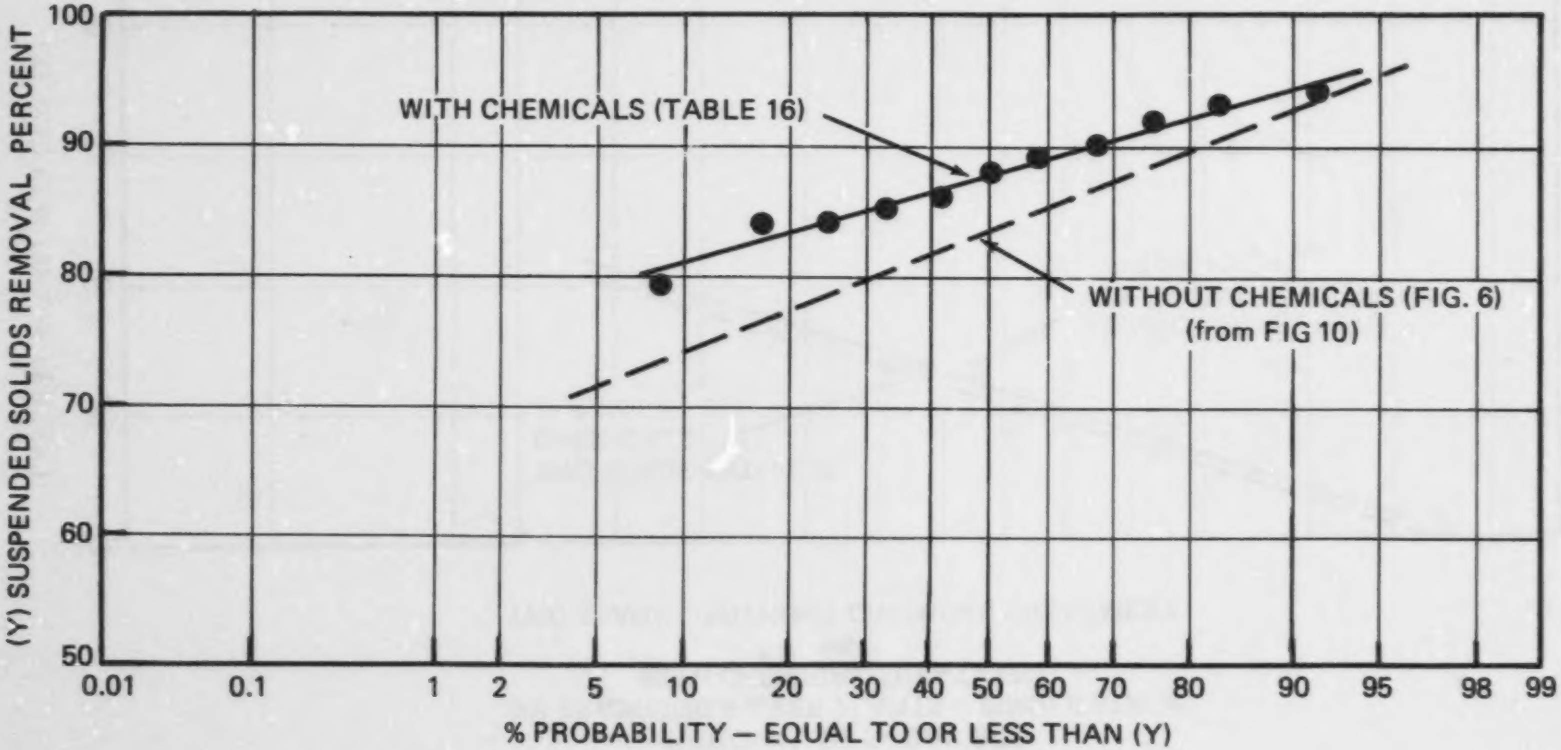


FIG. 13
REMOVAL OF 5–DAY BOD
BY TRICKLING FILTER PLANTS – SINGLE STAGE
WITH CHEMICAL TREATMENT
VS
TWO STAGE – WITHOUT CHEMICAL TREATMENT

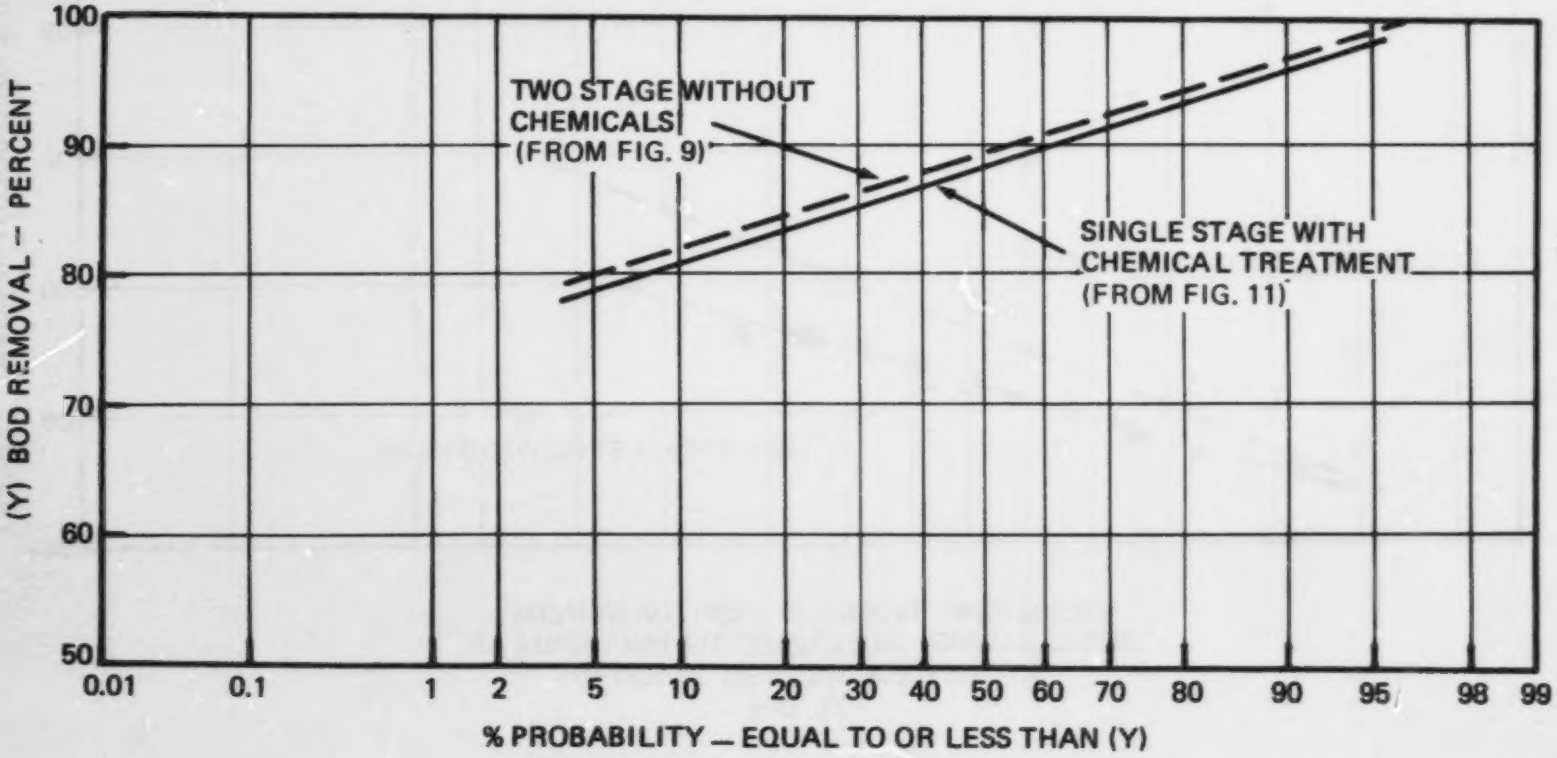


TABLE 21
EFFECT OF CHEMICAL TREATMENT ON REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS AT SINGLE-STAGE TRICKLING FILTER PLANTS

Treatment	No. of Plants	BOD$_5$			Susp. Solids		
		Raw	FE	% Rem.	Raw	FE	% Rem.
		Mg/l	Mg/l		Mg/l	Mg/l	
Without Chemicals	16	164	41	75	182	37	80
With Chemicals							
Rock Media	9	192	21	89	174	22	87
Plastic Media	5	125	18	86	194	18	91
All	14	170	20	88	181	21	88

309 are greater than those at plant 314. This may be attributable to the periodic high concentration of suspended solids observed in the primary settling tank effluent of the latter plant during the period of study.

Observations and Conclusions

The detailed information on chemical treatment and its effects on overall plant performance at 14 plants studied provided a firm basis for the following observations and conclusions:

1. Performance at four single-stage and one two-stage trickling filter plant was greatly enhanced by the addition of metal salts and polymers to precipitate phosphorus and removal of a high proportion of colloids by agglomeration and flocculation. Equally effective performance was experienced at a sixth plant where lime is added following the trickling filter and its settling tank in a flocculator clarifier.

2. Overall removal of BOD_5 at these six plants was increased on the average from 75 to 87% and suspended solids removal increased from 81 to 89%. This reduces the load in BOD_5 and suspended solids on the waters receiving the plant effluent by approximately 45%. The five-day BOD and suspended solids in the effluent averaged 21 mg/l and 19 mg/l, respectively.

3. Concentrations of BOD_5 and suspended solids in the effluent and overall percent removals at eight other plants studied were at very similar levels.

4. No apparent difference was observed in performance of plants with zero or very low recirculation and those with recirculation ratios as high as 3.0. There is a general belief, however, among most of the operators of these plants that a certain degree of recirculation is beneficial to overall performance.

5. No observable relationship between hydraulic or organic loadings and performance was apparent over the range of rates found in these 14 plants. (See Table 18).

6. No apparent differences were observed in removal of BOD_5 and suspended solids between filters with rock media and those with plastic media. Both hydraulic and organic loadings were of similar magnitude in terms of volume of media and are typical of loadings generally classified as low to intermediate rates.

7. Physical alterations for the storage, application and mixing of the chemicals and polymers are quite simple and can be provided for at low capital cost. Usually, existing plant facilities are adequate for mixing and contact periods.

8. Ferric chloride is most commonly used at these plants by reason of its ready availability in Michigan. Dosage to remove 80% of total phosphorus usually ranges from 25-45 mg/l as $FeCl_3$. Substantial improvements in BOD_5 and suspended solids removal generally occurred when total phosphorus was reduced to 2.0 mg/l or less.

9. Extremely low wastewater and air temperatures appeared to reduce removals of BOD_5 and suspended solids but to a lesser degree at plants employing chemical treatment.

10. The effect of increased solids loading on sludge treatment facilities did not necessitate modifications to existing facilities at the plants studied. Although more supernatant is produced and substantially increased loadings on primary settling tanks and trickling filters resulted, plant performance did not deteriorate.

11. In general, chemical treatment by the methods described in this report is an extremely effective method of upgrading single-stage trickling filters, which is easily managed and involves a relatively low cost.

UPGRADING WITH ADDITIONAL TREATMENT WORKS

Several trickling filter plants with facilities for upgrading filter plant effluent quality were studied. Each is typical of a quite common class of facilities.

Mixed Media Gravity Filters

Mixed media gravity filters were placed in service at plant 304 in June 1973 to upgrade the quality of effluent from a two-stage trickling filter system with chemical treatment for removal of phosphorus. The effluent from the filters had a BOD_5 and suspended solids of about 16 mg/l.

Facilities are shown schematically on the sheet entitled, "Flow Pattern" in the Appendix. Additions consisted of flocculation tanks installed between the trickling filters and the final settling tanks and three 4,500 gpm pumps to feed final settling tank effluent to the four mixed media filters. Provisions are included for surface washing and backwashing the filters by either manual or automatic control. Each of the four filters are divided in two sections, each 10 ft x 10 ft. Media consists of 9" of gravel, 3" of high density garnet, 4 1/2" of larger garnet, 9" of silica sand and 16 1/2" of coal for a total depth of 42". Loading rates average 4,000 gpd/ft^2 (2.8 gpm/ft^2).

Each section is equipped with two surface wash arms just above the media, with effluent troughs for the backwash. Surface washing and backwashing are activated by an alarm when the head loss reaches about 10 ft. This occurs in 18-24 hours. Surface wash rates are about 500 gpm. Backwash pumps operate at a low rate of 1800 gpm and high rate of 3,600 gpm, using stored final effluent from the clear well. The cycle is completed in about 10 minutes. Backwash water flows by gravity to the plant inlet.

Rates of flow through the plant are controlled by diverting instantaneous flows in excess of about eight MGD to a flow equalization chamber. Flow to the mixed media filters is held constant at a rate of about 7.2 MGD. This uniformity enhances performance of the filters.

The flocculation tanks can be operated for chemical flocculation, straight aeration, or short-term activated sludge. Each method has been tried. The most effective method is to operate as high rate, short-term activated sludge with about 2,500 mg/l suspended solids in the mixed liquor.

Studies were conducted by plant personnel first by applying chlorine ahead of the mixed media filters to inhibit biological activity for a period of time. The point of chlorine application was then changed to the clear well following the filters and resulted in a very low final chlorine residual. The study gave convincing proof that a significant portion of the BOD removal is attributable to biolgical activity rather than simply a straining process for removal of solids.

Performance data in the Appendix indicates that in 1973-74 the mixed media filter system reduced BOD_5 in the trickling filter effluent from 16 mg/l to 9 mg/l and suspended solids from 16 mg/l to 5 mg/l at surface loading rates of 4,050 gpd/ft^2 (3.1 gpm/ft^2). Expressed in terms of effluent loadings, 970 lbs BOD_5 in the final settling tank effluent was reduced to 545 in the mixed media filter effluent, while suspended solids dropped from 970 lbs to 309 lbs. Discussion with the plant superintendent revealed that during the summer and fall of 1976, BOD_5 averaged 5 mg/l and 305 lbs/day while suspended solids average 2 mg/l and 125 lbs/day. This represents removal of 95% BOD_5 and 98% suspended solids by the total plant on a relatively weak sewage. This improvement over the 1973-74 period is attributed in large measure to the beneficial effects of the activated sludge process compared with straight aeration ahead of the mixed media filters and also the steady rate of flow.

Gravity Sand Filters - Mechanically Backwashed

Facilities at plant 306 consist of two-stage trickling filters without intermediate sedimentation, followed by gravity sand filters. Ferric chloride and polymers are added to the raw sewage for removal of phosphorus. Sludge from the final settling tanks is brought back to the raw sewage wet well by gravity at a rate which is paced with the rate of sewage flow. Pump rates are kept nearly constant at 2.1 MGD by means of variable speed pumps. The chlorinated final settling tank effluent is pumped to the sand filters at a 3.0 MGD constant rate.

The sand filter system is comprised of a complex of 50 adjoining chambers which are 12 inches wide by 12.5 feet in length. Filter media consist of sharp washed sand, to a depth of 11 inches, laid on fine-slotted ceramic tile at the bottom of each channel. Underdrains convey the filtered effluent to the outfall sewer with about two-thirds of the effluent recycled after mixing with the final settling tank effluent.

The sand filters are backwashed with final effluent at a low rate by means of a traveling pumping system. Controls are set to backwash twice daily for about 50 minutes at noon and midnight unless head loss reaches 18 inches in a shorter time. Backwash water is returned to the final settling tanks. Digester supernatant and filtrate from the filter press are conveyed to the raw sewage wet well.

The sand filter effluent averaged 4 mg/l BOD_5 and 5 mg/l suspended solids during the 12 months, June 1973 - May 1974, with little or no difference in winter and summer months, as indicated by the data in the Appendix. With trickling filter effluents containing 24 mg/l BOD_5, this represents a reduction from 236 lbs to 39 lbs or 83% removal from the trickling filter effluent; correspondingly a reduction from 168 lbs suspended solids to 49 lbs or 71% removal from the trickling filter effluent. Overall plant removals are 99% of the BOD_5 and 98% of the suspended solids.

Chlorine feed rates are vey low because of the relatively low chlorine demand of the final settling tank effluent.

Intermittent Sand Filters

The open, underdrained, intermittently fed sand filters at plant 169 are typical of this commonly found supplementary treatment process.

The filters are used to upgrade the quality of the trickling filter effluent during summer months when climatic conditions at this northern cold climate location are favorable. As noted on the data sheet, which includes monthly averages from January 1975 - June 1976, the filters were operated for five months, June through October in 1975. Favorable temperatures and field conditions in 1976 permitted commencement of operation on April 1.

The sand filters consist of four beds, each 20 ft x 80 ft, underdrained to the point of plant discharge. Media is comprised of 24 inches of sharp sand atop 9 inches of graded 1/8 - 1 inch gravel. The original sand had an effective size of 0.6 - 0.9 mm and uniformity coefficient less than 2.5. Requirements for replacements have been less rigid.

Plant facilities preceeding the sand filters consist of a grit chamber, screening, raw sewage pump station, two primary settling tanks, a trickling filter, a final settling tank, a sludge digestion tank and open sludge drying beds. Digester supernatant and underdrainage from the sludge drying beds are discharged to the raw sewage pump station. Sludge from final settling tanks is returned to the raw sewage pump station. The final settling tank effluent is disinfected with chlorine.

Trickling filter effluent for the 18 months of study averaged 40 mg/l for both BOD_5 and suspended solids. Sand filter effluents for their eight months of operation averaged 8 mg/l BOD_5 and 9 mg/l suspended solids. Thus quantities of BOD and suspended solids were reduced from about 175 lbs in the trickling filter effluent to about 35 lbs in the sand filter effluent. Overall plant removal on a quite weak raw sewage averaged 91% BOD_5 and 92% suspended solids at sand filter loadings of 13 gpd/ft^2 or 0.57 MGAD.

Discussions with the plant superintendant reveal that the sand filters show no sign of operating less effectively at the end of the five-month summer operation. In his opinion, these filters could be operated continuously at these loadings with equal effectiveness.

Pressure Mixed Media Filters

At plant 302, four pressure sand filters, each consisting of steel cylinders, 9ft in diameter and 15 ft long with dished ends, provide approximately 600 ft^2 of filter area. Media consists of layers from top to bottom of 20 inches of 1.0 mm anthracite, 20 inches of 30-40 mesh garnet and 9 inches of No. 6 mesh garnet. Filtering and backwashing are controlled automatically. Normal backwash rate is 16 gpm/ft^2 for about 3-5 minutes.

Plant facilities preceeding the pressure filters consist of screening, ferric chloride fed ahead of an aerated grit chamber followed by introduction of a polymer ahead of primary settling tanks, a pumping station, three trickling filters and two final settling tanks. The effluent from the settling tanks is pumped to the pressure filters. The filter effluent is then disinfected with chlorine before discharge. There are two heated anaerobic sludge digestion tanks. Supernatant is returned to the raw sewage wet well.

Trickling filter effluent for the 12 month study period averaged 31 mg/l BOD_5 and 19 mg/l suspended solids. Pressure filter effluents averaged 22 mg/l BOD_5 and 7 mg/l suspended solids. Overall plant removal on a quite strong raw waste averaged 93% BOD_5 and 94% suspended solids. Quantities in the trickling filter effluent were reduced from 500 lbs BOD_5 to 350 lbs and from 310 lbs suspended solids to 115 lbs.

Summary of Fine Media Filter Performances

The effectiveness of the four filter processes in upgrading the quality of trickling filter effluents is summarized in Table 22 below.

TABLE 22

Type of Filter	Dosing Rate gpd/ft^2	BOD_5 FE mg/l	BOD_5 FME mg/l	BOD_5 % Removal tot.plant	SUSP. SOLIDS FE mg/l	SUSP. SOLIDS FME mg/l	SUSP. SOLIDS % Removal tot.plant
Pressure-mixed media - backwashed	3200	31	22	93	19	7	94
Gravity - mixed media - backwashed	4050	16	5	95	15	2	98
Gravity - sand backwashed	2400	24	4	99	17	5	98
Intermittent - sand	13	40	8	91	40	9	92

FE = Trickling Filter Effluent
FME = Fine Media Effluent

Stabilization or Oxidation Ponds

Several plants were studied where trickling filter effluents are upgraded by means of supplemental ponds. Three such plants were selected where facilities are typical of those providing a high quality effluent and where extensive reliable analyses and flow records are available.

Aerated and Short-Term Stabilization Ponds

The trickling filter at plant 117 is followed by an aerated pond and a stabilization pond. The effluent is then distributed evenly over a 20 acre peat absorption bed. The plant consists of the usual components: screening, pumping, grit removal, primary sedimentation, single-stage trickling filters and final settling tanks. Effluent is pumped to the aerated lagoon. Sludge is digested in a heated anaerobic digester followed by an unheated sludge storage tank. Storage sludge is withdrawn periodically to a sludge lagoon. Supernatant is also discharged to the lagoon.

The aerated pond is three acres in area and six feet deep. The pond provides a detention time of about six days for average flows of 0.93 MGD treated during the 12 months study period. Aeration is provided by a floating surface type aerator with a 15 hp motor which theoretically supplied oxygen at a rate of 1,350 lbs/day. Loading on this pond averaged 310 lbs BOD_5 and 285 lbs suspended solids per day, as noted in the monthly averages summarized with other information in the Appendix for this plant. Removal of both BOD_5 and suspended solids is quite consistent during the year, averaging 55% and 8%, respectively.

The overflow from the aerated pond passes to a stabilization pond with a surface area of 25 acres and a water depth of three feet. Detention time at the observed average flow rate of 0.93 MGD is about 25 days. Effluent quality is seven mg/l for both BOD_5 and suspended solids. The poorest performance occurred in April, undoubtedly associated with accelerated anaerobic biological activity as the ice cover melted and temperature rose in the lagoon.

Performance on a total treatment facility basis is as follows: 2,000 lbs of BOD_5 in the raw sewage was reduced to 55 lbs for over 97% removal; and 1,980 lbs of suspended solids reduced to 55 lbs for 97% removal.

Long-Term Stabilization Pond

At plant 121, six waste stabilization ponds totalling 540 acres are used to upgrade the quality of the effluent of an ordinary trickling filter plant which consists of screening, pumping, grit removal, primary sedimentation, single-stage filters and final sedimentation. Sludge from final settling tanks is returned to the raw sewage pumping station. Sludge treatment is accomplished by two heated digesters followed by two secondary digesters. Digested sludge is discharged to open drying beds and supernatant is piped to the primary sedimentation tanks. Underdrainage of sludge drying beds is discharged to the raw sewage pumping station.

The plant effluent is pumped to the waste stabilization ponds which occupy one square mile. There are six ponds, each with a surface area of 90 acres. Five are operated in parallel, the sixth serving as a secondary pond. Each of the five primary ponds are operated in turn, filling for a period of 20-30 days depending on rainfall and evaporation rates. The pond is then discharged to the secondary pond where it is held for about 20-30 days before discharge. Late in the fall the contents of all primary ponds are lowered for winter storage during ice cover and discharged quite rapidly in the spring after which the regular fill, hold and discharge cycle is followed. Time of discharge is governed to some extent by river flow conditions.

Operational data for both the plant and the ponds are summarized in Table 23 and in the Appendix. The trickling filter plant effluent is quite typical of single-stage filters in the northern climate averaging about 55 mg/l BOD_5 and 45 mg/l suspended solids. The effluent is upgraded to values of 6-15 mg/l BOD_5 and 10-15 mg/l suspended solids on an annual basis. Thus the loading on the receiving stream is reduced from about 2,800 lbs BOD_5 per day in the trickling filter effluent to about 875 lbs and the loading from the plant is completely eliminated in the ponds by storage during three winter months. Overall removals by plant and pond are in the order of 95% of the BOD_5 and 93% of the suspended solids.

Although analyses are not made on nitrogen, it is reasonable to expect that considerable nitrification takes place in the ponds with ammonia dropping to very low levels. This was the experience at plant 160. The effluent from this Imhoff tank and trickling filter plant required a great deal of upgrading to meet a rigid effluent requirement including a very low ultimate BOD.

Ponds were constructed on State owned property, consisting of three cells with piping for either parallel or series operations. Maximum water depth was 10 fect, providing a theoretical detention time of about 100 days at the average 1.1 MGD flow. Table 24 summarizes performance during calendar year 1971. During the previous November, the lagoons were drawn down moderately when stream flows were relatively high. Storage during December brought all of the ponds to the 10 ft stage, ready for series flow-through operation, for the winter months as indicated in the schematic flow diagram in the Appendix.

The values for percent removal in Table 24 represent overall performance for the total facility, which includes the filter plant and ponds. It is interesting to note that the filters substantially reduced ammonia values each month of the year by more than 50%, increasing to about 60% during the summer. The residual ammonia was lowered to less than 0.5 mg/l during warm summer months. Annual averages were 13.6 mg/l NH_3-N in the raw sewage, 5.8 mg/l in the filter plant effluent and 0.81 mg/l in the pond effluent. Correspondingly, total phosphorus was 6.1 mg/l in the raw wastewater, 4.8 mg/l in the filter effluent and 1.1 mg/l in the ponds effluent.

TABLE 23
REMOVAL OF BOD$_5$ BY TRICKLING FILTERS AND STABILIZATION PONDS
121 N.D.

Month 1975-76	Sew. Flow MGD	PONDS Discharge MGD	BOD$_5$ – Lbs/Day x 1000 Raw	 Filter Eff.	 Lagoon Eff.
November	5.41	18.55	10.53	2.39	0.93
December	4.91	8.24	8.53	2.54	0.62
January	5.10	0	10.14	2.81	0
February	5.45	0	10.51	2.59	0
March	6.66	0	13.24	3.00	0
April	6.53	8.08	13.20	3.27	1.01
May	6.09	8.28	10.42	3.00	0.83
June	6.38	0	10.76	2.66	0
July	6.25	8.49	10.33	2.24	0.78
August	5.93	0	11.24	2.38	0
September	5.78	9.17	9.94	3.09	0.77
October	5.77	14.35	10.31	2.84	1.08
Averages	5.86	6.29	10.76	2.73	0.05

TABLE 24
PERFORMANCE OF TRICKLING FILTER PLANT & STABILIZATION PONDS
160 Mich.

1971 Month	Inf. Flow MGD	pH –	D.O. mg/l	S.S. mg/l	 % Rem.	BOD$_5$ mg/l	 % Rem.	Ammonia mg/l	 % Rem.	Phosphorus mg/l	 % Rem.	BOD$_{20}$ mg/l	BOD$_{20}$ filterd mg/l
January	35.78	8.2	9.3	18	90	4.6	98	1.40	80	2.01	58		
February	33.99	7.9	9.2	23	88	8.9	95	1.67	80	2.37	55	14.1	
March	36.18	8.2	8.5	27	85	7.2	95	0.95	89	2.52	52	13.6	
April	34.02	8.4	8.2	50	70	10.7	93	0.87	91	2.20	61	33.0	
May	38.47	8.8	7.7	93	45	19.5	87	0.77	94	1.04	80	33.0	
June	34.96	9.0	8.7	82	53	22.0	87	0.52	98	0.57	85	37.0	23.0
July	34.36	9.5	10.1	66	63	15.0	90	0.46	96	0.35	92	34.0	19.0
August	33.30	9.8	9.9	44	73	10.0	95	0.21	98	0.16	97		
September	31.12	9.6	10.1	33	82	7.0	97	0.21	98	0.15	98		
October	32.16	9.4	9.7	25	86	7.0	97	0.17	99	0.14	98		
November	31.86	8.8	10.6	29	82	6.0	97	0.70	84	0.85	88		
December	32.99	8.4	12.0	29	84	8.0	97	1.78	92	1.13	73		
Average	33.62	8.8	9.5	43	75	11.0	94	0.81	92	1.12	78	27.5	21.0
Low		7.9	7.7	18	45	4.6	87	0.17	80	0.14	52	13.6	
High	(403.68)	9.8	12.0	93	90	22.0	98	1.78	99	2.52	98	37.0	

Composited samples

Flow Pattern: January 1 through May 16th – flow through to river at 10.0 ft. stage.
May 17 through November 8th – storing in series.
November 8 – 23rd. – discharging to river
November 24th to December 31st. – Storing in series.

TABLE 25
REMOVAL OF BOD AND SUSPENDED SOLIDS BY TRICKLING FILTERS & ACTIVATED SLUDGE
403, Minn.

Month 1973	Sew. Flow MGD	5-Day BOD Raw mg/l	FE mg/l	% Rem Raw-FE	Susp. Solids Raw mg/l	FE mg/l	% Rem Raw-FE
January	2.8	334	19	94	162	7	96
February	2.8	276	17	94	162	6	96
March	3.4	281	14	95	203	7	97
April	3.2	323	8	98	190	4	98
May	3.1	302	14	95	188	5	97
June	2.9	297	10	97	199	12	94
July	2.8	262	4	98	202	8	96
August	2.8	303	6	98	182	7	96
September	3.9	280	5	98	144	5	97
October	3.5	324	15	95	190	9	95
November	3.1	345	11	97	173	6	97
December	3.1	406	14	97	205	7	97
Average	3.1	311	11	96	183	7	96

TABLE 26
REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS BY TRICKLING FILTERS AND ACTIVATED SLUDGE
402, Minn.

Month 1975-76	Sew. Flow MGD	BOD$_5$ Raw mg/l	FE mg/l	% Rem	Susp. Solids Raw mg/l	FE mg/l	% Rem
August	1.04	657	27	96	336	20	94
September	1.11	552	26	95	406	26	94
October	1.07	553	22	96	377	13	97
November	0.98	592	26	96	411	19	95
December	0.95	602	29	95	430	27	94
January	0.47	771	32	96	577	37	94
February	0.46	646	28	96	661	59	91
March	0.48	620	17	97	623	25	96
April	0.48	495	17	97	599	42	93
May	0.79	425	22	95	474	24	95
June	0.96	426	28	93	319	19	94
July	0.92	428	16	96	298	20	93
Averages		564	24	96	459	28	94

The stabilization ponds reduced BOD_5 levels from about 17 mg/l in the filter influent to 11 mg/l in the pond effluent, removing about 35% from an excellent filter plant effluent for overall removal of 94%. Suspended solids in the pond effluent remained at about the same level as the trickling filter effluent on an annual basis. Unquestionably, algae cells accounted for a high proportion of the final solid concentrations.

Activated Sludge

Several plants were studied where activated sludge follows trickling filters. A variety of flow patterns and loadings are used. At plant 403, for example, flow from the primary sedimentation tanks is divided in two equal parts. One-half is pumped to a trickling filter, the other half to the activated sludge reactors. The effluent from the settling tank following the trickling filter mixes with the primary effluent going to the aeration tanks. Filter effluent and activated sludge mixed liquor are returned to the raw sewage wet well and recycled to the primary sedimentation tanks with the raw wastes. Loading on the activated sludge system is about 75 lbs of BOD_5/1,000 ft^3. Average detention time is four hours including return activated sludge. Raw BOD_5 is reduced from 311 mg/l to 11 mg/l and suspended solids from 183 mg/l to 7 mg/l representing 96% removal of both as shown in Table 25.

At plant 402 the trickling filter effluent is discharged directly to the activated sludge process without intermediate settling. A strong waste averaging 564 mg/l BOD_5 for the 12 months studied is reduced to 24 mg/l in the plant effluent for 96% reduction. Correspondingly, 94% of the suspended solids in the 459 mg/l raw waste is removed leaving 28 mg/l in the plant effluent. Equally good performance is accomplished throughout the year as may be noted from Table 26.

Data were reviewed at four other plants in Minnesota where trickling filters are followed by activated sludge. Overall performance of the six plants is summarized in Table 27 below.

TABLE 27

REMOVAL OF BOD_5 AND SUSPENDED SOLIDS BY TRICKLING FILTERS FOLLOWED BY ACTIVATED SLUDGE ANNUAL MEAN OF MONTHLY MEANS

Municipality	Flow MGD	BOD_5			SUSP. SOLIDS		
		Raw	Eff	% Rem	Raw	EFF	% Rem
401 MN	4.69	191	9	95	170	22	94
402 MN	0.82	564	24	96	459	28	94
403 MN	3.13	311	11	96	184	7	96
404 MN	0.28	248	9	96	344	26	92
405 MN	2.22	222	12	95	293	17	94
406 MN	0.65	153	11	93	162	15	91
Averages		281	13	95	269	19	93

Observations and Conclusions

A rather wide variety of supplementary treatment processes for upgrading trickling filter effluents were examined. Extensive data from several typical full-scale field installations were studied and summarized in this report. Selection of the method to be used is dependent on many considerations and circumstances related to the individual installation. Performance capability of the several processes for improvement of trickling filter effluent quality is reflected in the following summary (Table 28).

TABLE 28
UPGRADING TRICKLING FILTER EFFLUENTS
BY ADDITIONAL TREATMENT PROCESSES

Tertiary Process	**BOD_5**			**Susp. Solids**		
	Filter Eff.	**Tert. Eff.**	**% Rem.**	**Filter Eff.**	**Tert. Eff.**	**% Rem.**
	mg/l	**mg/l**	**Raw-Final**	**mg/l**	**mg/l**	**Raw-Final**
A. Fine Media Filters with Backwashing						
1. Mixed Media-Gravity	16	5	95	15	2	98
2. Mixed Media-Pressure	31	22	93	19	7	94
3. Sand-Gravity	24	4	99	17	5	98
B. Sand Filters-Intermittent	40	8	91	40	9	92
C. Waste Stabilization Lagoons						
1. Short Term Following Aerated Lagoons	18	7	97	18	7	97
2. Long Term – 1 Plant	56	10	95	47	13	93
Long Term – 1 Plant	17	11	94	47	43	75
D. Activated Sluge – 6 Plants	ND	13	95	ND	19	93

ACKNOWLEDGEMENTS

The information set forth in this report is, in large measure, the product of the combined efforts, cooperation and interest of staff engineers and technicians in the water pollution control agencies of Michigan, Minnesota, North Dakota, Pennsylvania, and Wisconsin, and the plant superintendants and operators of all of the plants for which data were provided for the in-depth field performance studies. A great many of these people not only furnished facts and figures but, very importantly, provided valuable insight and understanding of day to day operations, problems and solutions and shared in many of the value judgements expressed herein. Their participation, assistance and counsel are gratefully acknowledged.

APPENDIX

The Appendix contains key information on facilities, loadings and performance of 26 trickling filter plants discussed in this report. Raw data for each plant on physical features, daily records of sewage flow and temperatures and laboratory analyses were furnished by the responsible state regulatory agencies and plant superintendants.

These plants were selected from a large number of municipal facilities of similar designs, modes of operation, loadings and overall performance. Daily records for each plant, usually for two or more years, were examined in order to establish normal loadings and performance of the plant.

Flow patterns are shown for each plant. Routing of wastewater through the unit processes, points of recirculation and points of discharge of digester supernatant and other sludge fractions are indicated. These flow diagrams are not drawn to scale nor do they necessarily portray the shape or number of units such as pumping stations, settling tanks, etc.

Plants are grouped alphabetically by classification as single-stage, two-stage, those with chemical treatment and those followed by additional facilities.

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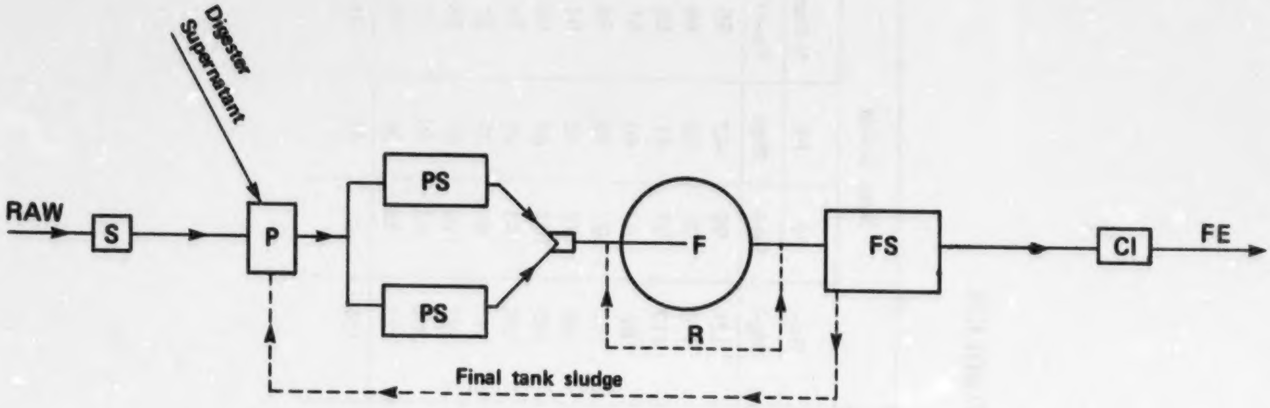
FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
107, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTER

1-80 ft. Diam.–6 ft. deep
Area = 0.115 Acres
Volume = 30,160 cuft.

Loading

Hydraulic @ Average Flow = 1.07 MGD and R = 1.3 MGD = 2.37 MGD

$$= \frac{2.37}{0.115} = 20.6 \text{ MGAD} = 475 \text{ gd/sqft}$$

Organic @ 99 mg/l in PE

$$= \frac{1.07 \times 8.35 \times 99}{30.16} = 29.3 \text{ \#/1000 cuft}$$

FINAL SETTLING TANK

1-45' Diam. Area = 1,590 sqft.
Surface Overflow rate @ 900 GPM Pump rate

$$= \frac{1,285,700}{1590} = 800 \text{ gals/day/sqft}$$

SLUDGE TREATMENT AND DISPOSAL

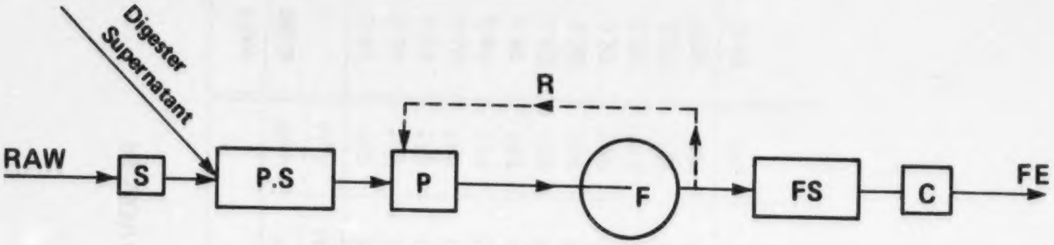
1–Digester 30' Diam. 20 ft. deep
vol. = 14,150 cuft.
Digested sludge to open drying beds
Supernatant to raw sewage wet well

TABLE A-1
REMOVAL OF BOD AND SUSPENDED SOLIDS
107 MICH.

Month	Raw Sew. Temp.	Sew. Flow	5-Day BOD				Susp. Solids			
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.
(1973)	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
Jan	53	1.14	153	92	45	71	121	95	42	65
Feb	52	1.07	104	89	47	55	116	90	40	66
Mar	51	1.61	123	86	36	71	117	87	41	65
Apr	51	1.93	79	68	34	57	82	87	40	51
May	54	1.11	121	105	49	60	110	97	38	65
June	59	1.15	112	82	45	60	109	79	42	61
July	62	0.63	150	128	49	67	152	107	52	66
Aug	62	0.76	165	122	48	71	185	93	38	79
Sept	64	0.82	148	102	47	68	173	85	32	81
Oct	63	0.62	170	132	44	74	187	126	41	78
Nov	62	0.67	192	130	32	83	200	83	46	77
Dec	58	1.32	93	62	27	71	113	65	34	70
Avg	–	1.07	134	99	42	69	139	91	41	71

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
110, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTER

1-68 ft. Diam.

Area = 3,630 sqft. = 0.083 Acres

Volume = 21,800 cuft.

Loading

Hydraulic @ Average Flow = 0.4 MGD and R - 1.25

$$= \frac{0.4 \times 2.25}{0.083} = 10.8 \text{ MGAD} = \frac{900000}{3630} = 250 \text{ gpd/sqft}$$

Organic

$$= \frac{0.4 \times 8.35 \times 151}{21{,}800} = 23 \text{ lbs/1000 cuft}$$

Primary settling tank is IMHOFF Tank

SLUDGE TREATMENT AND DISPOSAL

1-Digester-15,500 cuft.

Supernatant to Imhoff tank

Digested sludge to open drying beds

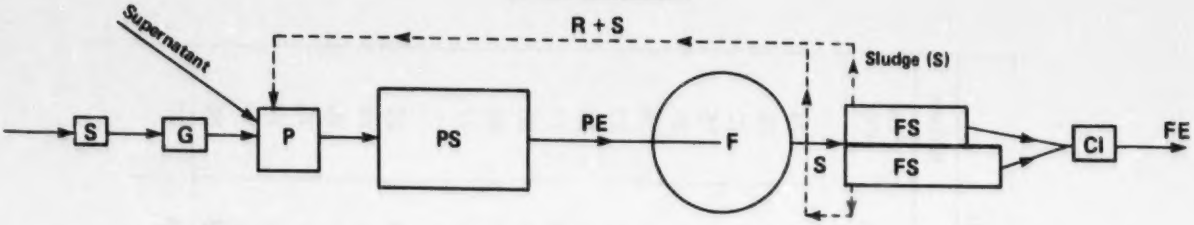
CHEMICAL TREATMENT—None

TABLE A-2
REMOVAL OF BOD AND SUSPENDED SOLIDS
110 MICH.

Month	Flow	5-Day BOD				Suspended Solids			
	MGD	Raw	PE	FE	% Rem.	Raw	PE	PE	% Rem.
(1973)		Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
January	0.43	192	144	34	82	164	82	22	87
February	0.39	185	157	39	79	191	99	28	85
March	0.49	183	151	36	80	165	91	27	84
April	0.58	152	116	31	80	127	70	25	80
May	0.47	177	141	36	80	159	94	26	84
June	0.49	157	145	44	72	148	105	34	77
July	0.42	176	147	26	85	169	93	20	88
August	0.38	197	142	32	84	192	97	17	91
September	0.32	218	146	32	85	218	107	17	92
October	0.29	214	161	28	87	204	95	17	92
November	0.27	222	175	24	89	214	113	16	93
December	0.26	269	190	38	86	248	103	17	93
Average	0.40	195	151	33	83	183	96	22	88

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
112, MICH

FLOW PATTERN



CAPACITIES AND LOADING

FILTER

1-75 ft. Diam. 6 ft. deep
Area = 4,420 sqft. = 0.101 Acres
Volume = 30,000 cuft.

Loading

Hydraulic @ Average Flow (0.77 MGD) plus R = 0.5-1.0

$$= \frac{1.35}{0.101} \quad 13.4 \text{ MGAD} \sim \frac{1{,}350{,}000}{4420} = 305 \text{ gals/day/sqft}$$

Organic: Assume 35% Removal in PS tanks

$$= \frac{224 \times 0.65 \times 8.35}{30} = 40.5 \text{ lbs BOD}_5 \text{ /1000 cuft}$$

FINAL SETTLING TANKS

1-47 ft. by 14 ft. by 10 ft. = 670 sqft. = 6,700 cuft.
1-62 ft. by 16 ft. by 7 ft. = 992 sqft. - 6,944 cuft.
Total surface area = 1,662 sqft.

$$\text{surface overflow rate} = \frac{770{,}000}{1662} = 465 \text{ gals/day/sqft}$$

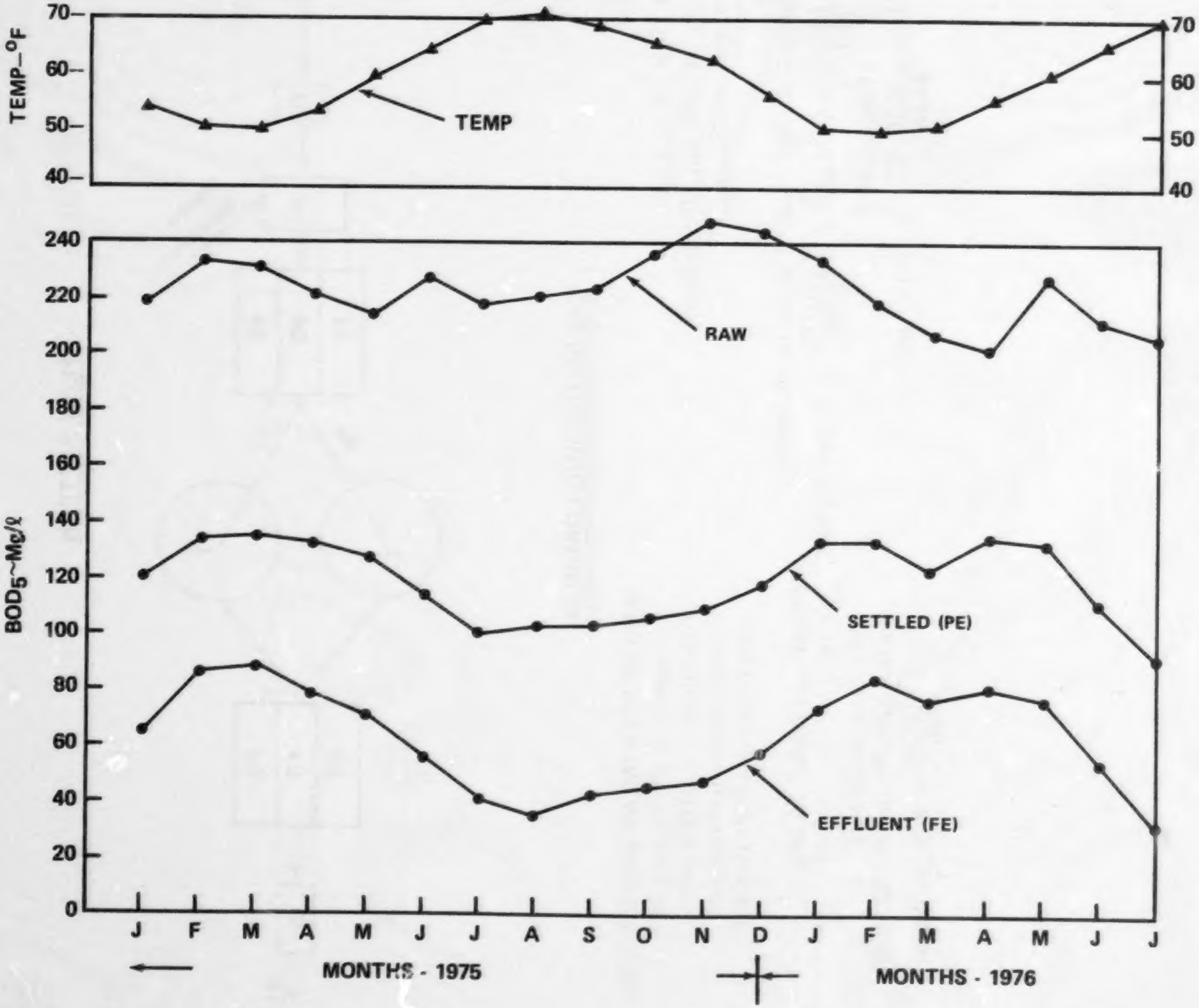
SLUDGE TREATMENT AND DISPOSAL

1-Primary Digester—30 ft. Diam.-13,400 cuft.
1-Secondary Digester—40 ft. Diam.—25,100 cuft.
Digested sludge to open drying beds
Supernatant to raw sewage pump station

TABLE A-3
REMOVAL OF BOD AND SUSPENDED SOLIDS
112 MICH.

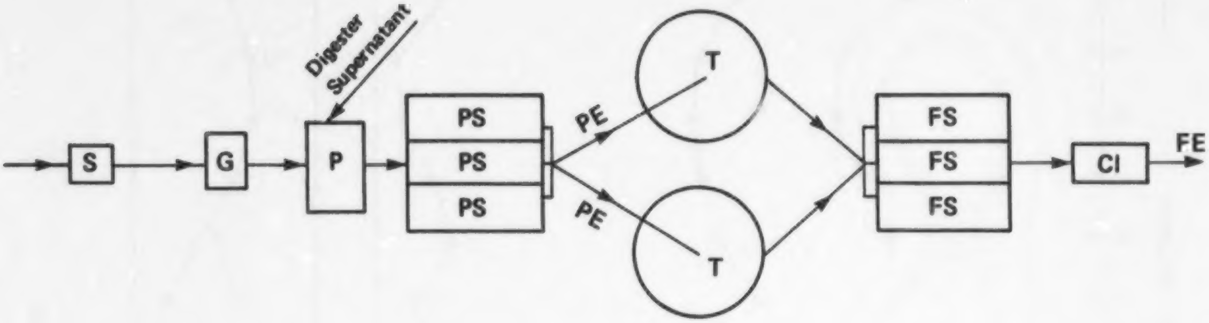
Month	Raw Sew. Temp. °F	Flow MGD	5-Day BOD				Susp. Solids			
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.
			Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
1975										
Jan	53	0.74	219	120	65	70	243	116	65	73
Feb	51	0.74	233	134	86	63	256	118	63	75
Mar	51	0.77	231	135	89	61	265	123	73	72
Apr	54	0.91	222	134	79	64	259	121	64	75
May	60	0.83	215	128	70	67	240	119	72	70
June	65	0.76	228	115	57	75	252	103	64	75
July	70	0.69	219	100	40	82	252	82	46	82
Aug	71	0.75	221	102	36	84	238	85	39	84
Sept	69	0.68	224	104	43	81	220	97	50	77
Oct	66	0.64	236	105	46	81	280	120	56	80
Nov	63	0.63	249	110	48	81	282	99	51	82
Dec	57	0.71	245	119	58	76	262	102	59	77
1976										
Jan	52	0.63	234	133	74	68	244	104	62	75
Feb	51	0.90	219	134	85	61	239	90	61	74
Mar	52	0.97	208	124	77	63	318	106	67	79
Apr	57	0.86	203	135	81	60	234	110	64	73
May	60	0.86	228	133	78	66	276	115	72	74
June	66	0.84	211	111	53	75	251	94	57	77
July	70	0.78	206	91	33	84	253	79	38	85
Avg		0.77	224	119	63	72	256	104	59	77

FIGURE A-1
EFFECT OF SEWAGE TEMPERATURE
ON REMOVAL OF BOD_5
112 MICH



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
125, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS

2-100 ft. Diam.–6 ft. deep

Total Area = 15,700 sqft.–0.360 Acres

Total Volume–94,250 cuft.

Loading

Hydraulic @ Average Flow = 1.28 No recirculation

$$= \frac{1.28}{0.36} = 3.56 \text{ MGAD} = \frac{1,280,000}{15700} = 81 \text{ gals/day/sqft}$$

Organic @ 91 mg/l in PE

$$= \frac{1.28 \times 8.35 \times 91}{94.25} = 10.3 \text{ \#/1000 cuft}$$

SLUDGE TREATMENT AND DISPOSAL

2–Digesters @ 25,000 cuft. each

Total Volume = 50,000 cuft.

Digested sludge to drying beds

Supernatant (see Flow Pattern)

FINAL SETTLING TANKS

3-18′ x 45′

Total Area - 2,450 sqft.

Surface overflow rate @ 1.28 MGD

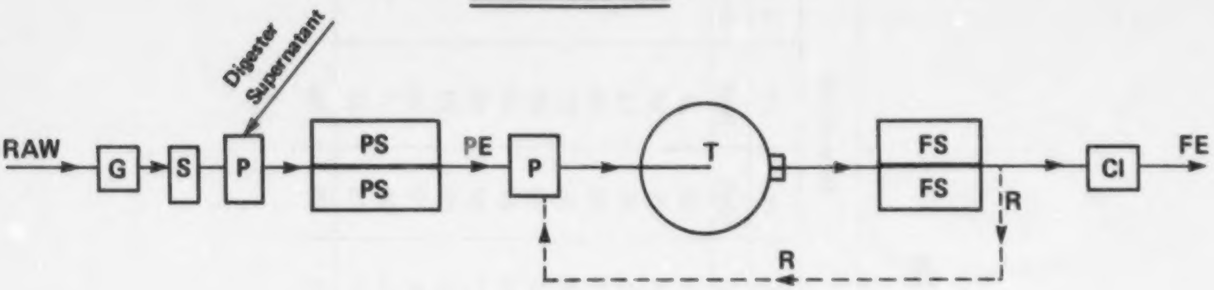
$$= \frac{1,280,000}{2450} = 522 \text{ gals/day/sqft}$$

TABLE A-4
REMOVAL OF BOD AND SUSPENDED SOLIDS
125 MICH.

Month	Raw Sew. Temp.	Sew. Flow	5-Day BOD				Susp. Solids			
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.
(1975)	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
Jan	52	1.26	130	98	40	69	141	88	34	76
Feb	50	1.36	122	88	39	68	145	81	36	75
Mar	50	1.37	130	101	47	65	164	95	45	73
Apr	51	1.57	142	103	40	72	177	93	46	74
May	55	1.63	156	98	32	79	178	88	37	79
June	58	1.37	137	86	30	78	193	98	49	75
July	61	1.17	130	79	23	82	198	94	42	79
Aug	64	1.17	150	82	22	85	217	82	33	85
Sept	62	1.16	134	89	25	81	159	80	27	83
Oct	59	1.08	160	99	32	80	206	90	38	82
Nov	57	1.12	142	95	33	77	205	96	37	82
Dec	54	1.15	119	74	28	76	147	75	33	78
Avg	–	1.28	138	91	32	77	178	88	38	79

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
132, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTER

1-70 ft. Diam. 6 ft. Deep
Area = 0.088 Acres ~ 3,850 sqft.
Volume = 23,000 cuft.

Loading

Hydraulic @ 0.94 plus R = 0.235 MGD = 1.175 MGD

$$= \frac{1.175}{0.088} = 13.4 \text{ MGAD} \sim \frac{1,175,000}{3850} = 305 \text{ gals/day/sqft}$$

Organic @ 65 mg/l in PE

$$= \frac{0.94 \times 8.35 \times 65}{23} = 22 \text{ \#/1000 cuft}$$

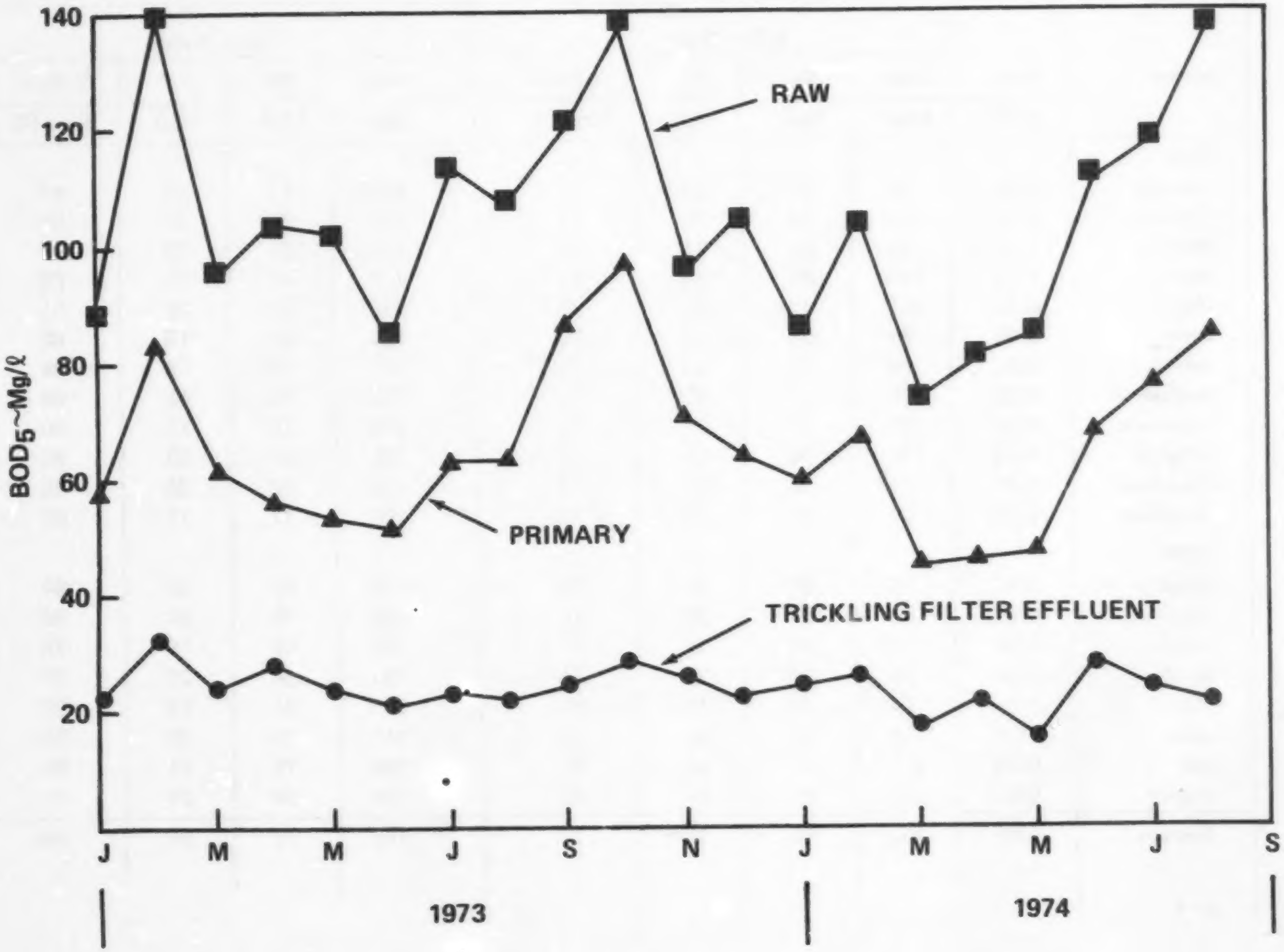
DIGESTERS-Sludge Treatment and Disposal

1—Primary @ 31,000 cuft.
1—Secondary @ 31,000 cuft.
Total Volume = 62,000 cuft.
Digester Supernatant to raw sewage wet well
Digested Sludge to open drying beds

TABLE A-5
REMOVAL OF BOD AND SUSPENDED SOLIDS
132 MICH.

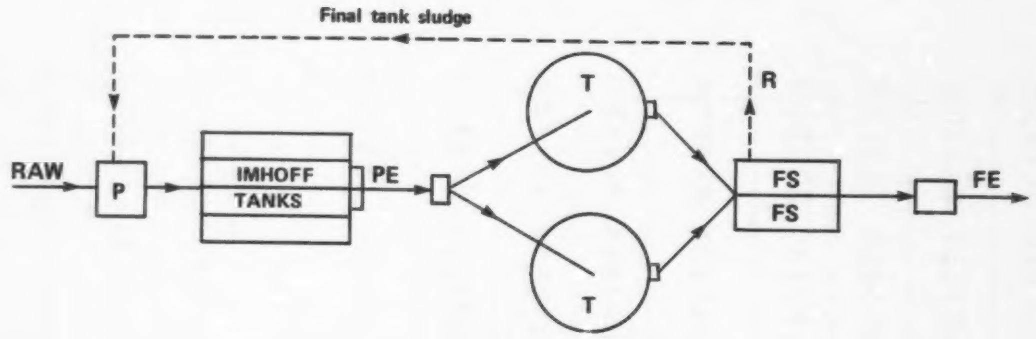
Month	Flow	5-Day BOD				Susp. Solids			
		Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.
	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
1973									
January	0.89	88	57	22	75	122	47	16	87
February	0.72	139	84	31	78	158	76	22	86
March	1.16	95	62	24	75	121	69	30	75
April	0.88	103	57	28	73	133	60	18	86
May	0.88	102	53	23	77	258	81	23	91
June	0.86	84	51	20	80	160	87	19	88
July	0.62	114	64	22	81	206	77	13	94
August	0.65	107	63	21	80	156	75	19	88
September	0.63	120	88	25	79	166	72	17	90
October	0.68	138	98	29	79	150	84	23	85
November	0.99	95	70	26	73	155	82	38	75
December	0.82	104	64	23	78	159	71	17	89
1974									
January	0.92	85	60	24	72	116	53	18	84
February	0.91	103	67	26	75	154	70	21	86
March	1.14	73	45	18	75	87	48	19	78
April	0.99	80	46	21	74	102	54	22	78
May	1.06	84	48	15	81	118	55	18	85
June	0.76	111	69	28	75	143	79	29	80
July	0.59	117	77	23	80	148	75	21	86
August	0.61	137	85	21	85	194	88	21	89
Average	0.94	104	65	23.5	77	150	70	21	86

FIG A-2
132, MICH. TRICKLING FILTER PLANT SHOWING
REMOVAL OF BOD_5



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
160, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS **FIXED NOZZLES**

2-92 ft Diam; 8 ft Deep
Total Area = 13, 295 sqft = 0.31 Acres
Total Volume = 108,000 cuft

Loading

Hydraulic @ 1.07 MGD R = 0.1 Flow = 1.17 MGD

$= \frac{1.17}{0.31} = 3.77$ MGAD; $\frac{1{,}070{,}000}{13295} = 80$ gals/day/sqft

Organic @ 153 mg/l in PE

$= \frac{1.07 \times 8.35 \times 153}{108} = 12.65$ #/1000 cuft

SLUDGE TREATMENT & DISPOSAL

By Imhoff tanks
Digested sludge to open drying beds

FINAL SETTLING TANKS

2-15′ x 40′ ~ Total Area = 1200 sqft

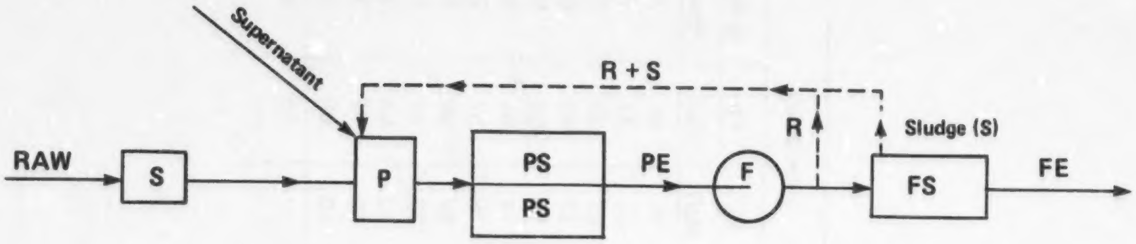
Surface Overflow Rate $= \frac{1{,}070{,}000}{1200} = 890$ gals/day/sqft

TABLE A-6
REMOVAL OF BOD AND SUSPENDED SOLIDS
160 MICH.

Month (1972)	Sew. Temp. °F	Flow MGD	5-Day BOD				Susp. Solids				NH_3-N		Total P	
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.	Raw	FE	Raw	FE
			Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Mg/l
January	69	1.02	225	156	25	89	178	97	34	81	11.7	5.5	6.4	5.1
February	70	1.03	229	165	21	91	186	112	36	81	13.5	5.0	6.9	5.3
March	70	1.08	225	163	23	90	188	107	40	79	11.9	4.7	6.7	5.1
April	71	1.16	232	164	16	93	183	106	52	72	11.4	4.3	6.1	4.9
May	75	1.16	203	152	15	93	167	75	47	72	13.4	5.1	5.9	4.9
June	76	1.07	217	153	13	94	187	85	48	74	17.3	7.2	6.2	4.9
July	NR	NR	NR											
August	79	1.04	191	138	9	95	190	92	53	72	15.3	6.4	6.4	4.6
September	77	1.02	193	141	7	96	172	88	52	70	14.8	6.4	5.7	4.5
October	76	1.06	189	130	23	88	191	81	47	75	14.7	6.3	6.1	4.6
November	72	1.06	231	138	16	93	199	93	47	78	13.9	6.7	5.9	4.6
December	70	1.13	279	185	25	91	213	91	59	72	12.0	5.9	5.2	4.5
Annual Avg.		1.07	219	153	17	92	187	93	47	75	13.6	5.8	6.1	4.8

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
163, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTER

1-52 ft Diam. 6 ft Deep
Area = 2124 sqft = 0.049 Acres
Volume = 12,750 cuft

Loading

Hydraulic @ Aug Flow = 0.41 MGD plus

R(0.3 MGD) = 0.71 MGD

$$= \frac{710{,}000}{2124} = 334 \text{ gpd/sqft} = \frac{0.71}{0.049} = 14.5 \text{ MGAD}$$

Organic @ 59 Mg/l in PE

$$= \frac{0.41 \times 8.35 \times 59}{12.75} = 15.8^{\#}/1000 \text{ cuft}$$

FINAL SETTLING TANK

1-62′ x 14′ x 6′-6″ SWD
Area = 868 sqft
Surface Overflow Rate @ 0.41 MGD

$$= \frac{410{,}000}{868} = 472 \text{ gpd/sqft}$$

Sludge to raw sewage pumping station

SLUDGE TREATMENT AND DISPOSAL

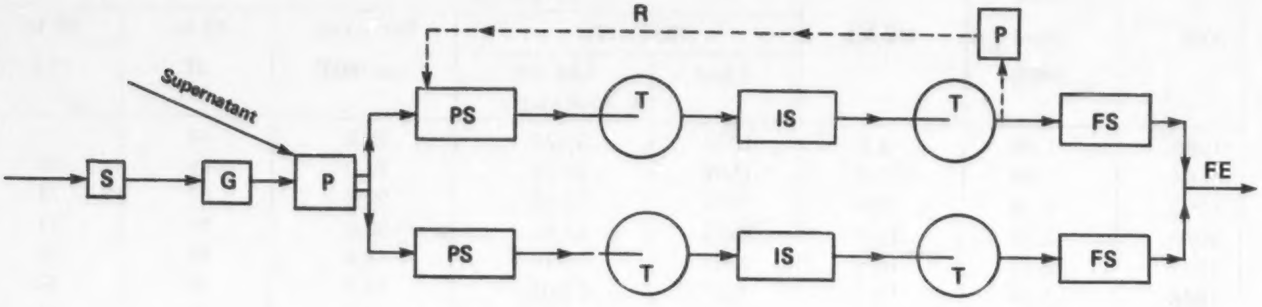
1-Digester 35′ Diam 20′-6″ Deep
Volume = 19,700 cuft
Digested sludge to open drying beds
Supernatant to raw sewage pumping station

TABLE A-7
REMOVAL OF BOD AND SUSPENDED SOLIDS
163 MICH.

Month	Raw Sew. Temp.	Sew. Flow	5-Day BOD				Susp. Solids			
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.
	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
Jan	53	0.38	121	58	29	76	183	75	41	78
Feb	52	0.38	112	64	25	78	145	67	33	77
Mar	50	0.50	97	57	26	73	134	67	39	71
Apr	51	0.71	82	44	25	70	100	57	43	57
May	56	0.42	113	63	30	73	147	79	55	63
June	60	0.40	117	60	29	75	152	74	64	58
July	65	0.32	124	60	29	77	171	78	52	70
Aug	67	0.37	115	55	26	77	193	82	50	74
Sept	65	0.37	132	57	27	80	167	77	58	65
Oct	64	0.28	134	66	30	78	220	92	63	75
Nov	62	0.26	139	65	31	78	231	99	71	70
Dec	57	0.50	96	54	36	63	150	80	68	55
Avg	–	0.41	115	59	29	75	158	77	53	66

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
213, MINN

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS

Primary Filters:

1-58′ Diam: Area = 2642 sqft = 0.0606 Ac.; Vol = 15850 cuft
1-77′ Diam: Area = 4657 sqft = 0.1069 Ac.; Vol = 27940 cuft
Total Area = 7300 sqft = 0.168 Ac.; Total Vol = 43,800 cuft

Loading

Hydraulic @ 2.4 MGD + R(1.1 MG) = 3.5 MGD

$$= \frac{3,500,000}{7300} = 480 \text{ gals/day/sqft}; \quad \frac{3.5}{0.168} = 21 \text{ MGAD}$$

Organic @ $2085^{\#}$ BOD$_5$ in PE

$$= \frac{2085}{43.8} = 47.6^{\#}/1000 \text{ cuft}$$

Secondary Filters:

2 filters same sizes as Primaries

Loading

Hydraulic @ 3.5 MGD = 480 gals/day/sqft
Organic @ $739^{\#}$ BOD$_5$ in IE

$$= \frac{739}{43.8} = 16.9^{\#}/1000 \text{ cuft}$$

Total System

Organic @ $2085^{\#}$ BOD$_5$ in PE

$$= \frac{2085}{87.6} = 23.8^{\#}/1000 \text{ cuft}$$

INTERMEDIATE SETTLING TANKS (IS)

2-54′ x 20′ x 12.5′ = 2160 sqft
1-67′ x 15′ x 9.5′ = 1005 sqft
Total Area = 3165 sqft
Surface Overflow Rate @ 3.5 MGD

$$= \frac{3,500,000}{3165} = 1100 \text{ gals/day/sqft}$$

FINAL SETTLINGTTANKS (FS)

2-67′ x 20′ x 9′
Area = 2680 sqft
Volume = 24000 cuft
Surface Overflow Rate @ 2.4 MGD

$$= \frac{2,400,000}{2680} = 900 \text{ gals/day/sqft}$$

SLUDGE TREATMENT AND DISPOSAL

1-Primary Digester — Volume = 100,000 cuft
1-Secondary Digester — Volume = 27,600 cuft
Digested Sludge partly to open drying beds, partly hauled wet to fields

TABLE A-8
REMOVAL OF BOD_5
213 MINN.
TWO STAGE TRICKLING FILTER PLANT

Year	Raw Flow MGD	MGAD	Loading on Primary Filter			% Removal	
			BOD in PE		Ths. cu.ft. per MGD	PE to IE	PE to FE
			(Lbs.)	Lbs. per 1000 cu.ft.			
1963	1.48	8.8	1347	30.76	29.6	64	75
1964	1.69	10.0	1552	35.44	27.6	65	79
1965	2.10	12.5	1613	36.83	20.9	61	77
1966	2.19	13.1	2085	47.61	20.0	54	71
1967	2.77	16.5	2267	51.76	15.8	65	82
1968	3.24	19.3	2787	63.63	13.5	69	83
1969	3.17	18.9	2673	61.94	13.8	67	81
1970	2.59	15.5	2357	53.82	16.9	70	75
Avg	2.40	14.4	2085	47.61	19.8	64	78

Legend:
PE = Primary settling tank effluent
IE = Intermediate settling tank effluent
FE = Final settling tank effluent

TABLE A-9
REMOVAL OF BOD AND SUSPENDED SOLIDS
213 MINN.

Month (1973)	Sew. Flow MGD	5-Day BOD			Susp. Solids		
		Raw Mg/l	FE Mg/l	% Rem.	Raw Mg/l	FE Mg/l	% Rem.
January	2.3	184	22	88	150	28	81
February	2.2	166	27	84	157	36	77
March	3.5	109	29	73	130	30	77
April	3.4	138	23	83	109	39	64
May	3.7	122	27	78	97	24	75
June	2.6	178	23	87	119	31	74
July	2.5	184	29	84	157	30	81
August	2.8	171	40	77	138	28	80
September	2.5	176	33	81	145	28	81
October	2.7	142	33	77	153	31	80
November	NR	NR	NR		NR	NR	
December	2.4	NR	NR		NR	NR	
Averages	2.8	157	29	82	136	31	77

TABLE A-10
BOD_5 REMOVAL AT
213 MINN.
TWO STAGE TRICKLING FILTER PLANT

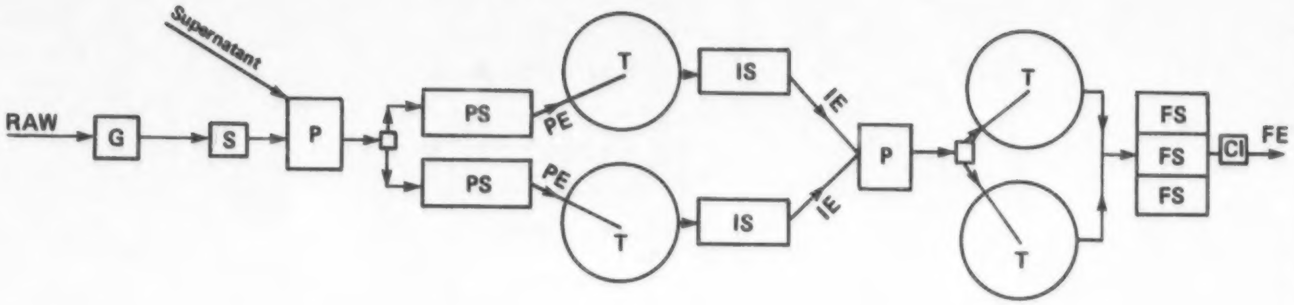
Headings:
PE—Primary Eff.; IE—Intermed Settling Tank; FE—Final Eff.

Year	No. of Samples	Flow	BOD_5 Through Plant													
			Raw		PE		IE		FE		Percent Removal					
		MGD	Mg/l	Lbs.	Mg/l	Lbs.	Mg/l	Lbs.	Mg/l	Lbs.	Raw-PE	PE-IE	Raw-IE	IE-FE	PE-FE	Raw-FE
1963	23	1.48	205	2533	109	1347	39	482	27	334	47	64	81	31	75	87
1964	17	1.69	189	2667	110	1552	39	550	23	325	42	65	79	41	79	88
1965	10	2.10	173	3034	92	1613	36	631	21	368	47	61	79	42	77	88
1966	11	2.19	179	3273	114	2085	53	969	33	603	36	54	70	38	71	82
1967	9	2.77	142	3284	98	2267	34	786	18	416	31	65	76	47	82	87
1968	11	3.24	167	4518	103	2787	32	866	18	487	38	69	81	44	83	89
1969	12	3.17	153	4050	101	2673	33	873	19	503	34	67	78	42	81	88
1970	5	2.59	144	3114	109	2357	33	714	27	584	32	70	77	18	75	81
1973		2.70	156	3517	101	2270	–	–	28	631	35	–	–	–	72	82
*Avg		2.40	169	3385	105	2085	37	739	23	452	38	65	78	38	78	86

*Excluding 1973 (Data incomplete)

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
219 WISC

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS

1-Primary 120′ Diam. Area = 11,304 sqft
1- Primary 170′ Diam. Area = 22,686 sqft
1-Secondary (fixed nozzles) = 59,840 sqft.
1-Secondary 200′ Diam. Area = 31,400 sqft.

LOADINGS

Hydraulic @ 10 MGD

Primary = $\frac{10,000,000}{33990}$ 294 gals/day/sqft

Secondary = $\frac{10,000,000}{91240}$ = 110 gals/day/sqft

Organic

Primary @ 95 mg/l BOD_5 = $\frac{10 \times 8.35 \times 95}{204}$ = 39 #/1000 cuft

Secondary @ 27 mg/l BOD_5 = $\frac{10 \times 8.35 \times 27}{550}$ = 4 #/1000cuft

INTERMEDIATE SETTLING TANKS

2-85′ Diam. Area = 11,350 sqft.

Surface overfow rate = $\frac{10,000,000}{11,350}$ = 880 gals/day/sqft

FINAL SETTLING TANKS

1-40′ x 40′; 1-50′ x 50′; 1-75′ x 75′ ~ Total Area = 9,725 sqft.

Surface overflow rate = $\frac{10,000,000}{9725}$ = 1028 gals/day/sqft

SLUDGE TREATMENT AND DISPOSAL

2-Primary Digesters Total Volume = 130,475 cuft.
2 Secondary Digesters Total Volume = 85,000 cuft.
Supernatant to raw sewage pumping station

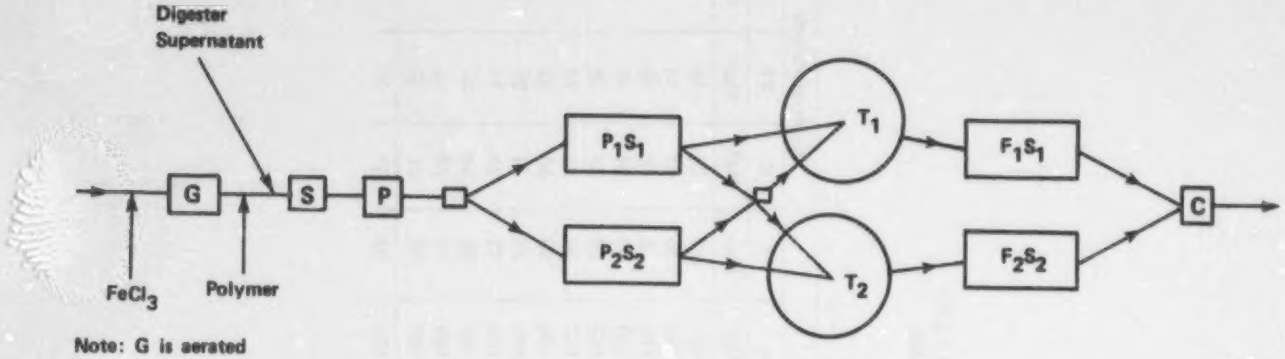
Note: Data on first stage facilities through IS (intermediate settling) reported in Table 1 and A-11 under plant 166 wi.

TABLE A-11
COMPARISON OF FIRST AND SECOND STAGE FILTERS IN REMOVAL OF BOD AND SUSPENDED SOLIDS
219 WISC.

IE = Intermediate Settling Tank Effl.

Month	Sew. Temp.		Sew.	5-Day BOD						Suspended Solids					
	Raw	FE	Flow	Raw	PE	IE	FE	% Rem.		Raw	PE	IE	FE	% Rem.	
(1974)	°F	°F	MGD	Mg/l	Mg/l	Mg/l	Mg/l	Raw-IE	Raw-FE	Mg/l	Mg/l	Mg/l	Mg/l	Raw-IE	Raw-FE
Jan	56	47	9.6	168	111	41	19	76	89	151	122	39	26	74	83
Feb	55	47	10.0	157	113	38	19	76	88	184	130	43	19	77	90
Mar	53	49	11.6	100	76	25	13	75	87	118	88	40	15	66	87
Apr	55	53	11.8	123	78	22	12	82	90	150	87	50	20	67	87
May	59	58	11.1	123	81	21	12	83	90	150	95	33	26	78	83
June	62	63	10.0	152	93	24	12	84	92	147	90	35	26	76	82
July	66	69	9.5	139	80	26	12	81	91	186	93	40	32	78	83
Aug	68	69	9.5	137	80	26	12	81	91	145	79	34	25	77	83
Sept	68	65	9.4	141	99	27	12	81	91	139	77	31	21	78	85
Oct	66	61	9.1	144	99	23	13	84	91	152	85	38	27	75	82
Nov	64	57	8.8	157	109	25	14	84	91	158	77	28	18	82	89
Dec	61	52	8.8	187	115	28	15	85	92	185	92	31	20	83	89
Avg	–	–	9.9	144	95	27	14	81	90	155	93	37	23	76	85

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
301, MICH



Note: G is aerated

CAPACITIES AND LOADINGS

FILTERS

1-68 ft. Diam.—6 ft. deep
1-70 ft. Diam.—6 ft. deep
Total Area = 7,480 sqft. = 0.1717 Acres
Total Volume = 44,500 cuft.

Loading:

Hydraulic @ Average flow = 0.64 MGD

$$= \frac{0.64}{0.1717} = 3.73 \text{ MGAD} \sim \frac{640{,}000}{7480} \text{ 85 gals/day/sqft}$$

Organic @ 61 mq/l. in primary effluent

$$= \frac{0.64 \times 61 \times 8.35}{44.5} = 7.3 \text{ Lbs BOD}_5 \text{ per 1000 cuft}$$

Note: Nov. to Apr. trickling filter T_1& F_1,$1S_1$ not operated

SLUDGE TREATMENT AND DISPOSAL

DIGESTERS:
1-30 ft. Diam., Vol = 10,900 cuft
1-45 ft. Diam., Vol = 23,950 cuft
Total Volume = 34,850 cuft.

Loading @ 975 #solids/day $= \frac{975}{34050} = 0.028$ #/cuft

Sludge disposal—sludge drying beds
Digester supernatant & sludge bed waterdrains (see above)

CHEMICAL TREATMENT FOR PHOSPORUS REMOVAL

See Flow Diagram above
Dosage: $FeCl_3$ 25-40 mg/l; Polymer 0.1-0.3 mg/l

FINAL SETTLING TANKS

1-12 ft. by 35 ft.; 1-35 ft. Diam.—Total Area = 1,358 sqft.

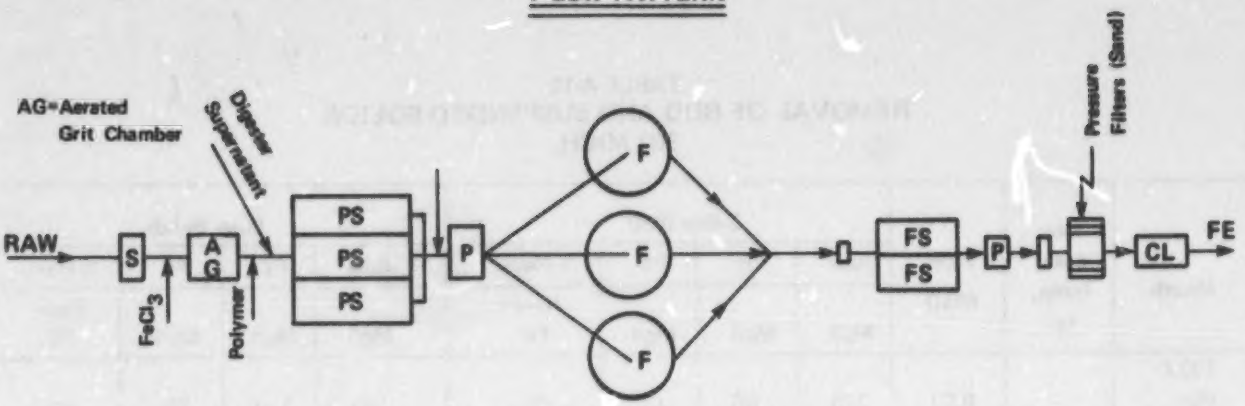
Surface overflow rate $= \frac{640{,}000}{1358} = 470$ gals/day/sqft

TABLE A-12
REMOVAL OF BOD AND SUSPENDED SOLIDS
301 MICH.

Month	Raw Sew. Temp. °F	Flow MGD	5-Day BOD				Susp. Solids			
			Raw Mg/l	PE Mg/l	FE Mg/l	% Rem. Raw-FE	Raw Mg/l	PE Mg/l	FE Mg/l	% Rem. Raw-FE
1974										
May	–	0.63	240	65	13	95	169	110	28	83
June	59	0.62	172	55	22	87	209	50	29	86
July	60	0.62	151	48	19	87	183	41	22	89
Aug	64	0.51	147	68	17	88	171	56	20	88
Sept	63	0.54	110	49	15	83	177	59	21	88
Oct	57	0.73	170	50	18	89	182	48	23	87
Nov	53	0I70	169	47	18	89	192	54	24	88
Dec	51	0.65	174	57	23	87	173	61	30	83
1975										
Jan	49	0.70	180	57	21	88	232	75	36	84
Feb	50	0.65	180	61	23	87	140	73	26	81
Mar	50	0.75	150	49	22	86	187	74	26	86
Apr	51	0.80	154	52	24	84	173	55	19	89
May	52	0.66	166	52	21	87	183	50	18	90
June	53	0.75	194	60	21	89	189	63	19	90
July	–	0.75	169	67	15	91	178	57	18	90
Aug	–	0.41	168	48	15	91	180	59	26	86
Sept	66	0.55	179	70	33	82	156	80	23	85
Oct	66	0.60	255	92	42	84	250	–	–	–
Nov	64	0.51	210	105	25	88	252	95	80	88
Dec	60	0.50	177	66	26	85	178	79	31	83
1976										
Jan	56	0.53	137	52	23	83	191	72	41	79
Feb	61	0.61	171	63	21	88	163	78	37	77
Mar	61	0.80	185	67	16	91	223	54	25	89
Apr	60	0.74	150	50	19	84	202	56	24	88
May	60	0.72	189	62	23	88	186	38	21	89
June	65	0.70	209	65	22	89	145	66	30	79
July	65	0.71	176	57	15	91	199	65	25	87
Avg		0.64	175	61	21	88	188	65	26	86

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
302, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS

3-115 ft. Diam-8 ft. Deep

Total Area = 31,160 sqft ~ 0.72 Acres

Total Volume = 250,000 cuft.

Loading

Hydraulic @ Average Flow = 1.93 MGD No R

$$= \frac{1.93}{0.72} = 2.70 \text{ MGAD} \sim \frac{1,930,000}{31,160} = 62 \text{ gals/day/sqft}$$

Organic @ 161 mg/l in PE

$$= \frac{1.93 \times 8.35 \times 161}{250} = 10.4 \text{ \#/1000 cuft}$$

FINAL SETTLING TANKS

2-65′ Diam 10′ swd

Total Area = 6636 sqft

Surface Overflow Rate@ 1.93 MGD

$$= \frac{1,930,000}{6636} = 290 \text{ gals/day/sqft}$$

TERTIARY TREATMENT

4-Pressure Sand Filters @ 9 ft. Diam

Total Area = 600 sqft. Loading = $\frac{1,930,000}{600}$ = 3200 gals/day/sqft

Media - 20″ - 1mm anthracite; 20″ 30-40 Mesh Garnet; 9″ No 6 Garnet

Backwash to raw sewage flow

DISINFECTION–2,000 #/day capacity–Chlorine Contact Chamber

CHEMICALS FOR PHOSPHORUS REMOVAL

Points of Application (see Flow Pattern)

FeCl$_3$–Ahead of Aerated Grit Chamber

Polymer–Quick mix then to pipe following aerated grit Chamber

Dosage Rates

FeCl$_3$–25-40 mg/l

Polymer–0.1 - 0.2 mg/l

SLUDGE TREATMENT AND DISPOSAL

Digesters

1-primary-33,780 cuft.

1-secondary-33,780 cuft.

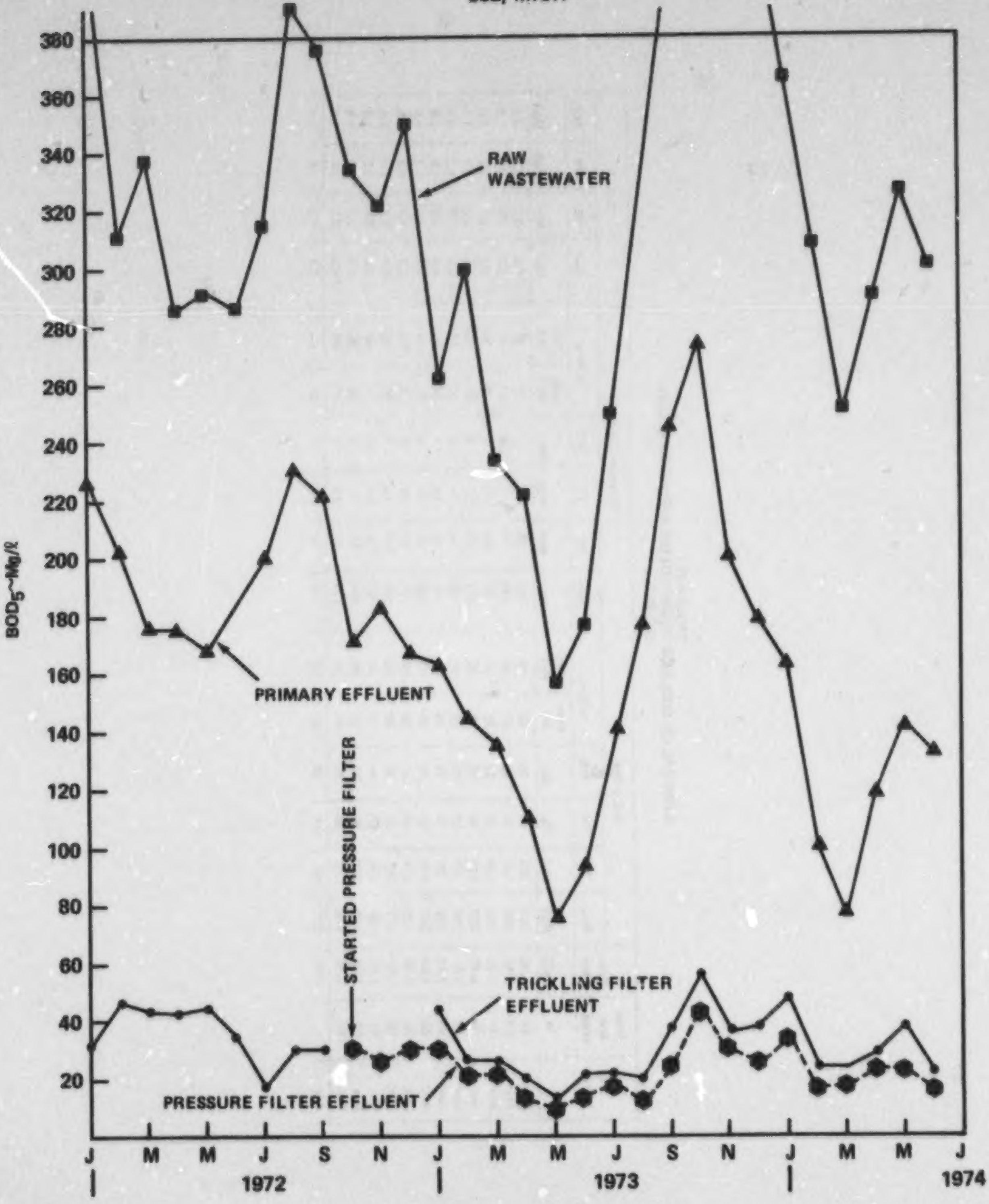
1-storage-50,000 cuft

Supernatant returned to primary settling tanks

TABLE A-13
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS
302 MICH.

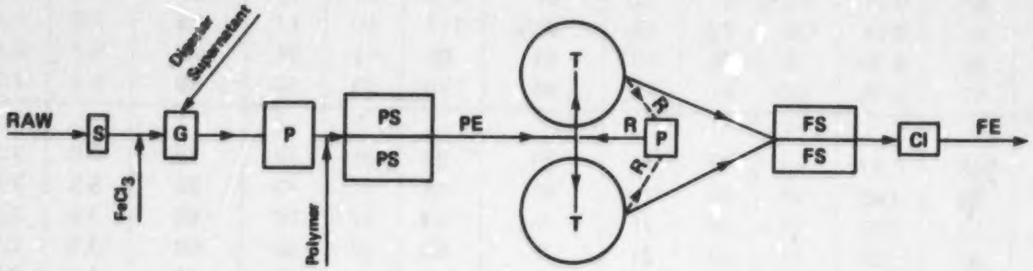
Month	Raw Sew. Temp.	Sew. Flow	5-Day Bod						Suspended Solids						Total P			
			Raw	PE	FE	PFE	% Rem.		Raw	PE	FE	PFE	% Rem.		Raw	PE	FE	PFE
	°F	MGD	Mg/l	Mg/l	Mg/l	Mg/l	Raw-PE	Raw-PFE	Mg/l	Mg/l	Mg/l	Mg/l	Raw-PE	Raw-PFE	Mg/l	Mg/l	Mg/l	Mg/l
Jan	51	1.95	261	163	45	30	83	89	102	19	23	8	77	92	5.5	3.1	2.1	1.9
Feb	NR	1.65	298	142	28	20	91	93	118	70	16	9	86	92	6.7	2.7	2.0	1.3
Mar	NR	1.94	233	136	28	21	88	91	91	59	13	4	86	96	5.8	2.1	1.2	1.0
Apr	56	2.45	222	110	20	15	91	93	101	42	11	4	89	96	4.6	2.0	1.1	1.1
May	58	2.37	156	72	13	10	92	94	89	38	12	5	87	94	4.1	1.5	1.2	0.8
June	60	2.47	176	93	21	15	88	91	91	68	15	7	84	92	4.9	2.5	1.7	1.4
July	66	1.93	249	142	22	19	91	92	123	90	18	9	85	93	6.8	4.9	1.7	1.5
Aug	70	1.78	406	177	20	11	95	97	97	97	18	5	81	95	7.1	4.3	1.8	1.5
Sept	69	1.67	517	245	38	25	93	95	146	220	21	7	86	95	8.0	5.4	1.7	1.4
Oct	67	1.61	480	274	57	44	88	91	145	104	41	12	72	92	8.9	6.5	2.5	1.8
Nov	60	1.59	510	201	36	30	93	94	164	57	20	9	88	95	8.9	3.2	2.2	1.8
Dec	56	1.70	420	178	39	25	91	94	155	49	20	10	87	94	8.5	3.2	2.1	1.8
Avg		1.93	327	161	31	22	91	93	118	76	19	7	84	94	6.7	3.6	1.8	1.4

FIG A-3
REMOVAL OF BOD$_5$
TRICKLING FILTERS AND PRESSURE FILTERS WITH CHEMICAL TREATMENT FOR PHOSPHORUS REMOVAL
302, MICH



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
303, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS

2-90 ft Diam 6 ft Deep
Total Area = 0.292 Acres ~ 12725 sqft
Total Volume = 76,300 cuft.

Loading

Hydraulic @ 0.43 MGD plus R = 1.53 MGD = 2.0 MGD

$$= \frac{2.0}{0.292} = 6.8 \text{ MGAD} \sim \frac{2{,}000{,}000}{12725} = 157 \text{ gals/day/sqft}$$

Organic @ 48 mg/l in PE

$$= \frac{0.43 \times 8.35 \times 48}{76.3} = 2.26 \text{ \#/1000 cuft}$$

DIGESTERS—Sludge Treatment and Disposal

1 Primary @ 12,700 cuft.; 1-Secondary-same
Total Volume = 25,400 cuft.
Digested Sludge to open drying beds
Supernatant to Grit Chamber

PHOSPHORUS REMOVAL

$FeCl_3$ & Polymer Feed—See Flow Pattern
Feed Rates: $FeCl_3$ @ 40± mg/l;
Polymer @ 0.3 mg/l

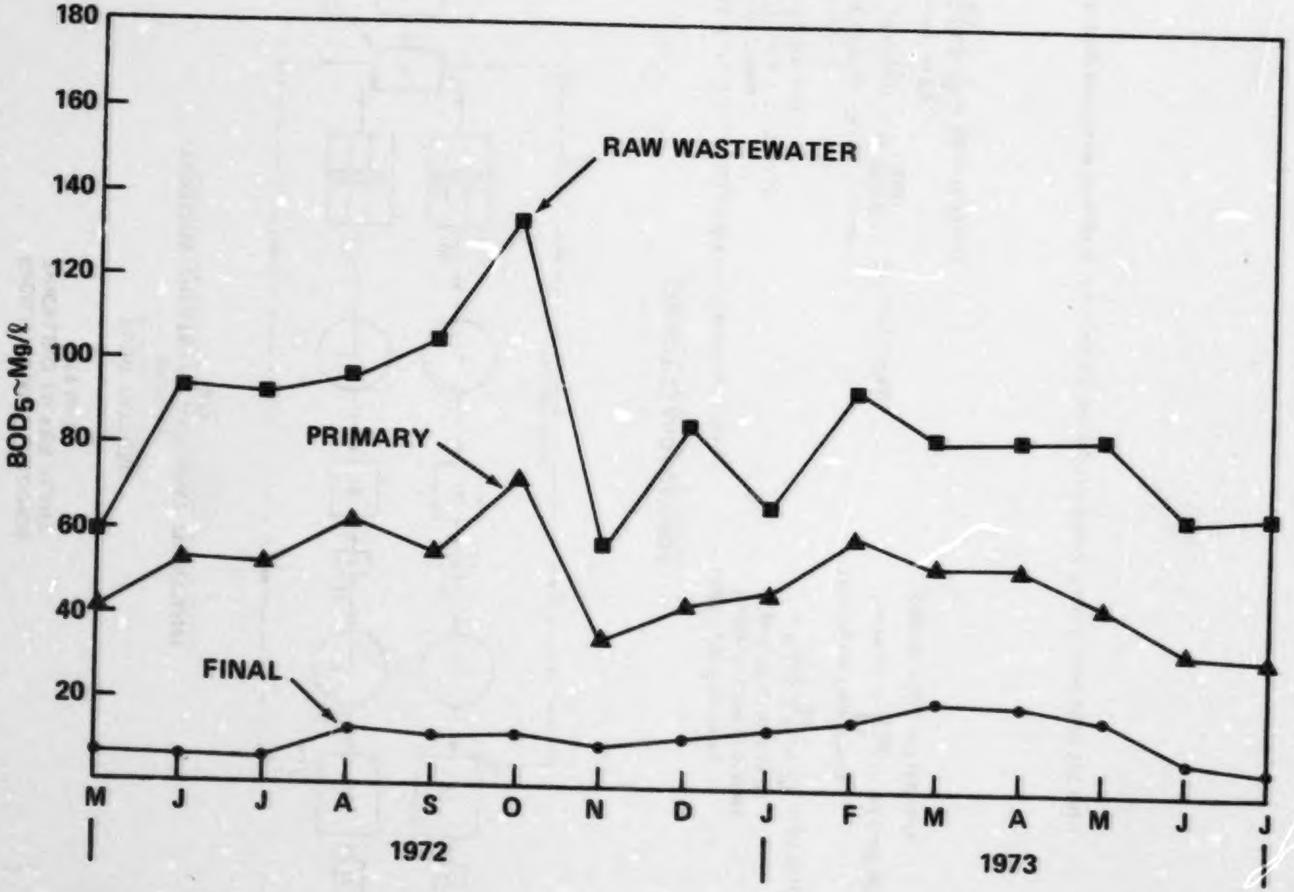
TABLE A-14

REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS

303 MICH.

Month	Sew. Temp.	Flow	5-Day BOD				Susp. Solids				Total P		
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.	Raw	PE	FE
1972	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l
May	58	0.44	59	41	8	86	85	53	5	94	5.1	2.4	1.0
June	63	0.29	93	53	8	91	107	58	5	95	7.7	3.3	1.2
July	66	0.27	92	52	8	91	130	58	9	93	7.7	3.2	1.4
August	67	0.26	97	62	13	87	111	59	18	84	8.0	4.6	2.7
September	68	0.27	106	57	12	92	113	44	14	88	6.9	2.2	1.3
October	64	0.24	133	73	13	90	117	45	17	85	7.8	2.7	1.3
November	58	0.39	58	36	10	83	89	50	24	73	5.7	2.4	1.2
December	52	0.39	85	44	12	86	118	50	14	88	6.2	2.2	0.6
1973													
January	48	0.47	68	47	15	78	80	61	17	79	5.0	2.7	0.6
February	46	0.43	93	60	18	81	98	61	12	88	5.5	2.8	0.7
March	53	0.52	84	53	21	75	89	62	28	69	3.8	2.2	0.9
April	53	0.52	84	53	21	75	89	62	28	69	3.8	2.2	0.9
May	58	0.57	84	44	19	77	115	58	34	70	4.7	2.6	1.3
June	64	0.52	63	34	9	86	72	45	31	57	4.8	2.3	1.3
July	67	0.46	66	32	7	89	80	41	22	73	5.3	2.4	0.8
August	68	0.41	68	32	5	93	113	41	19	83	6.4	2.7	0.7
September	69	0.35	119	46	11	91	142	41	14	90	7.9	3.3	0.7
October	67	0.31	126	58	12	90	127	47	10	92	8.9	3.6	0.8
November	61	0.33	130	67	11	92	117	55	10	91	8.8	4.3	1.0
December	55	0.42	91	57	16	82	79	54	13	84	5.9	3.6	1.6
1974													
January	47	0.66	67	45	19	72	72	61	17	76	4.5	2.8	1.1
February	47	0.52	66	50	21	68	79	61	20	75	4.7	3.5	1.8
March	48	0.57	52	36	17	67	59	40	19	68	3.5	2.1	1.2
April	51	0.53	64	37	19	70	68	40	25	63	4.6	2.3	1.6
May	56	0.51	62	31	17	73	67	40	33	51	4.1	1.9	1.7
June	61	0.43	76	38	17	78	80	43	33	59	5.2	2.1	1.7
Averages		0.43	84	48	14	83	92	51	19	79	5.9	2.8	1.2

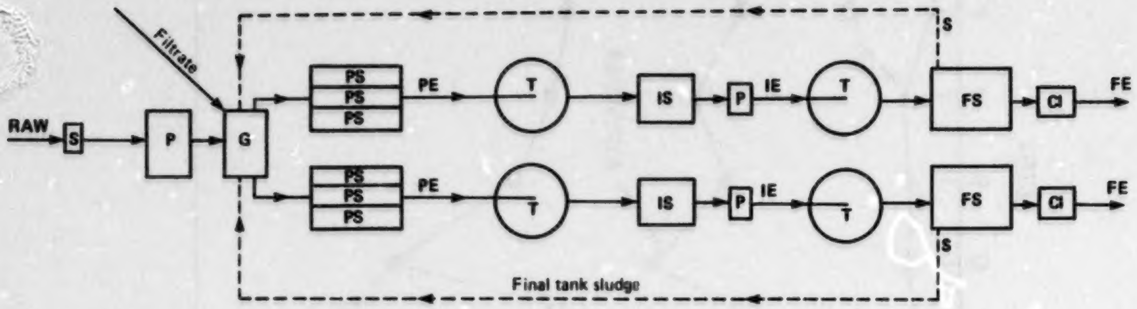
FIG A-4
BOD$_5$ REDUCTION
303, MICH



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
211 MICH

FLOW PATTERN

BEFORE
TERTIARY TREATMENT AND HEAT TREATMENT
1972



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Final tank sludge

CAPACITIES AND LOADINGS

FILTERS—PRIMARY—First Stage (SECONDARY ~ same capacity)

2–80 ft. Diam.–6 ft. deep

Total Area = 0.23 Acres ~ 10,050 sqft.

Total Volume = 60,000 cuft.

Loading on Primary

Hydraulic @ 6.20 MGD—No recirculation

$= \frac{6.20}{0.23} = 27\text{ MGAD} \sim \frac{6{,}2000{,}00}{10050} = 615\text{ gals/day/sqft}$

Organic @ 75 mg/l in PE

$= \frac{6.2 \times 8.35 \times 75}{60} = 65\text{ \#/1000 cuft}$

Loading on Secondary

Hydraulic same as primary

Organic @ 38 mg/l in IE

$= \frac{6.2 \times 8.35 \times 38}{60} = 33\text{ \#/1000 cuft}$

Loading on Total Filters

Hydraulic $= \frac{6.2}{0.46} = 13.5\text{ MGAD}$

Organic = 32.5 #/1,000 cuft.

Note: Data on first stage filter plant through IS (intermediate settling) reported in Table 1 under plant 139 Mich.

TABLE A-15
COMPARISON OF FIRST AND SECOND STAGE FILTERS FOR REMOVAL OF BOD_5 AND SUSPENDED SOLIDS
211 MICH.
TWO STAGE

Month	Raw. Sew. Temp.	Sew. Flow	5-Day BOD						Susp. Solids					
					Filters		% Rem.				Filters		% Rem.	
			Raw	PE	PRIM*	SEC			RAW	PE	PRIM*	SEC		
1972	°F	MGD	Mg/l	Mg/l	Mg/l	Mg/l	Pri. Filt.	Sec. Filt.	Mg/l	Mg/l	Mg/l	Mg/l	Pri. Filt.	Sec. Filt.
January	55	5.31	155	71	38	25	63	77	99	53	31	19	69	81
February	51	4.60	131	92	49	25	62	78	104	66	38	21	63	80
March	49	6.41	100	73	41	29	59	71	98	68	41	23	58	77
April	49	9.04	84	50	30	22	58	70	74	47	32	18	57	76
May	54	7.49	80	60	36	25	55	70	88	61	38	21	57	76
June	60	6.08	104	80	38	26	63	75	107	67	34	20	68	81
July	64	6.08	104	76	34	20	67	81	84	56	28	14	67	83
August	66	7.72	76	58	26	20	66	74	81	48	25	15	69	69
September	67	4.35	112	76	39	23	65	80	85	56	33	14	61	84
October	64	5.50	125	96	45	26	64	79	104	58	32	17	69	84
November	59	6.38	109	75	38	24	65	78	88	56	33	17	63	81
December	55	5.53	118	89	46	27	61	77	99	64	38	20	62	80
Averages		6.20	108	75	38	24	62	76	93	58	34	18	63	81

*Intermediate Settling tank (IS) effluent (designated plant 139 mi in Table 1).

304, MICH*
FACILITIES AND LOADINGS
TRICKLING FILTERS, GRAVITY SAND FILTERS AND WITH CHEMICAL TREATMENT
1973-74

TRICKLING FILTERS

TWO-STAGE

Total Area = 0.46 Acres

Total Volume = 120,000 cuft.

Loading on Total Filters

Hydraulic @ 7.26 MGD No Recirculation

$$= \frac{7.26}{0.46} = 15.8 \text{ MGAD}; \quad \frac{120{,}000}{7.26} = 16{,}500 \text{ cuft/MGD}$$

Organic @ 61 mg/1 in PE

$$= \frac{7.26 \times 8.35 \times 61}{120} = 30.8 \text{ \#/1000 cuft}$$

SAND FILTERS (MIXED MEDIA)

4 @ 400 sqft. = 1,600 sqft.–42" Deep

Loading

Hydraulic 3-4,500 GPM Pumps

$$@ 6.5 \text{ MGD} = \frac{4500 \times 1440}{1600} = 4050 \text{ gals/day/sqft}$$

@ 13.0 MGD = 8,100 gals/day/sqft.

Organic @ 16 mg/l in Filter Effluent

$$= \frac{6.50 \times 8.35 \times 16}{1600} = 0.543 \text{ \#/day/sqft}$$

= 540#/day/1,000 sqft.

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* Plant 211 Mich with addition of advanced treatment. (See Fig. 5A)

FIG A-5
FLOW PATTERN
TRICKLING FILTERS AND GRAVITY SAND FILTERS
304, MICH

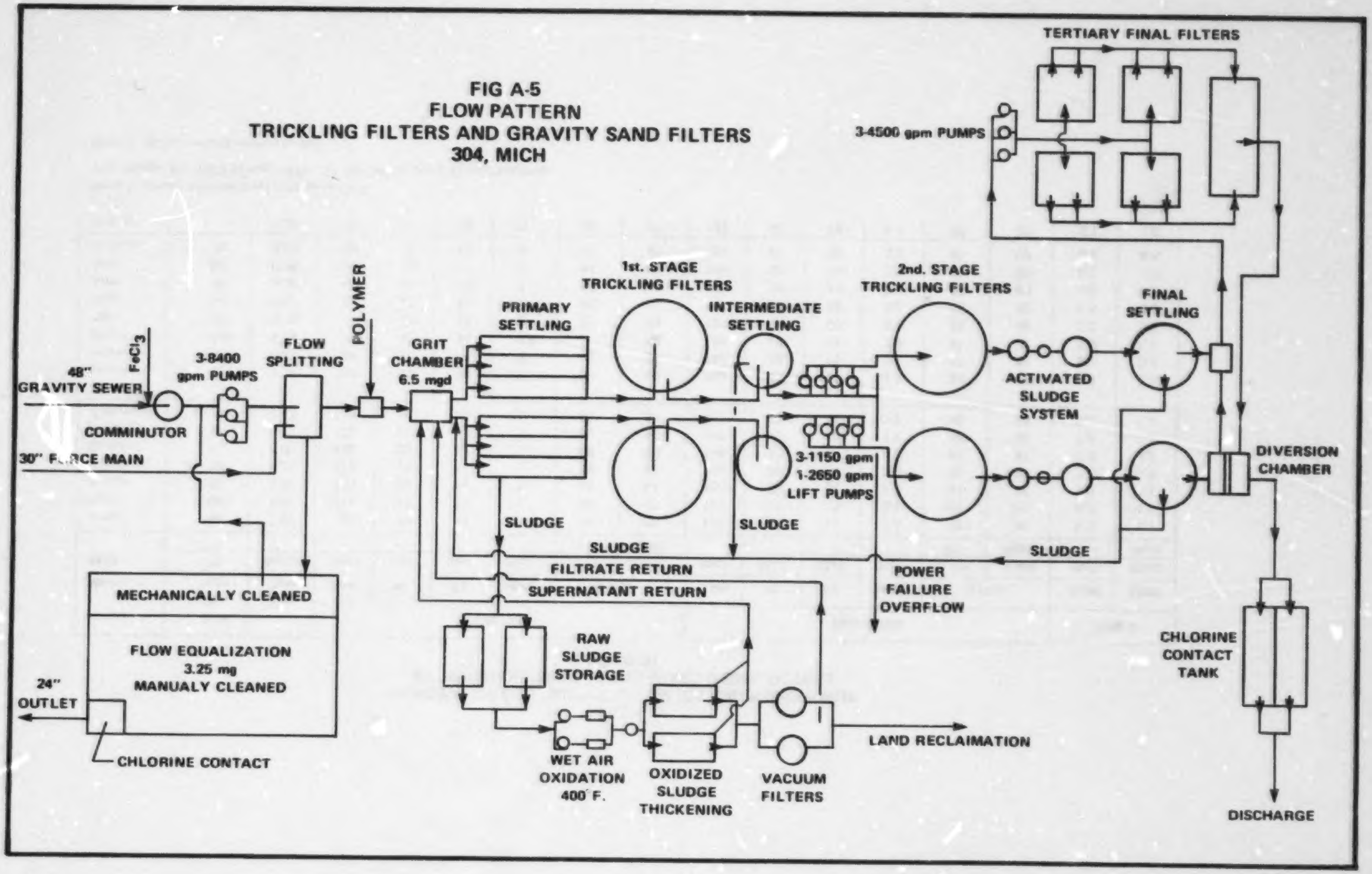

48" GRAVITY SEWER
$FeCl_3$
COMMINUTOR
30" F..RCE MAIN
3-8400 gpm PUMPS
FLOW SPLITTING
POLYMER
GRIT CHAMBER 6.5 mgd
PRIMARY SETTLING
1st. STAGE TRICKLING FILTERS
INTERMEDIATE SETTLING
3-1150 gpm 1-2650 gpm LIFT PUMPS
2nd. STAGE TRICKLING FILTERS
ACTIVATED SLUDGE SYSTEM
FINAL SETTLING
3-4500 gpm PUMPS
TERTIARY FINAL FILTERS
DIVERSION CHAMBER
CHLORINE CONTACT TANK
DISCHARGE
SLUDGE
SLUDGE
SLUDGE
SLUDGE
FILTRATE RETURN
SUPERNATANT RETURN
POWER FAILURE OVERFLOW
MECHANICALLY CLEANED
FLOW EQUALIZATION 3.25 mg MANUALY CLEANED
24" OUTLET
CHLORINE CONTACT
RAW SLUDGE STORAGE
WET AIR OXIDATION 400° F.
OXIDIZED SLUDGE THICKENING
VACUUM FILTERS
LAND RECLAIMATION

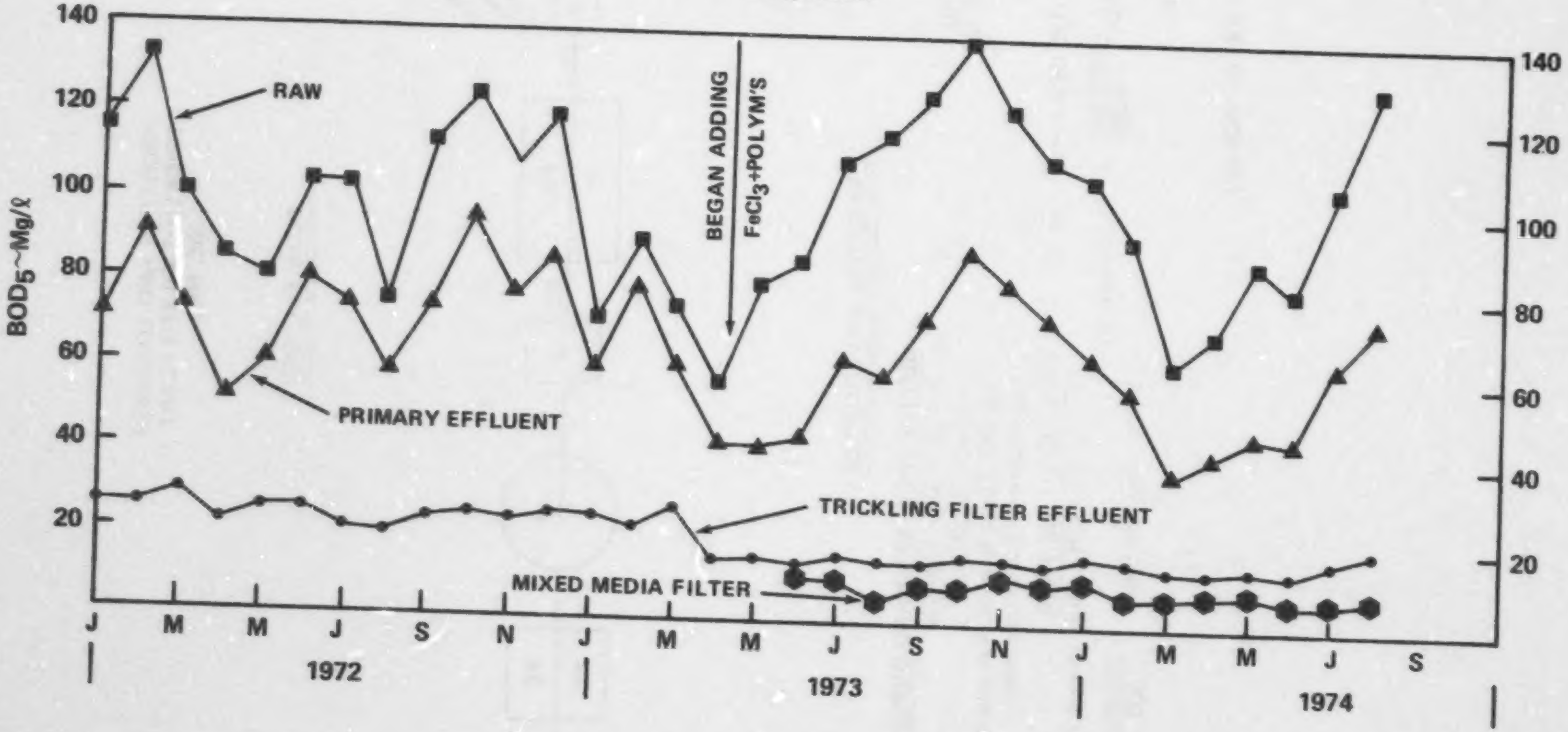
TABLE A-16
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS BY TRICKLING FILTERS AND MIXED MEDIA FILTERS
304 MICH.

Month	Raw Sew. Temp.	Sew. Flow	5-Day BOD						Susp. Solids						Total P	
			RAW	PE	FE	MME	% Rem.		RAW	PE	FE	MME	% Rem.		RAW	MME
1973	°F	MGD	Mg/l	Mg/l	Mg/l	Mg/l	RAW-FE	RAW-MME	Mg/l	Mg/l	Mg/l	Mg/l	RAW-PE	RAW-MME	Mg/l	MME Mg/l
June	60	7.85	86	43	14	11	84	87	129	36	14	5.4	89	96	5.0	1.1
July	66	5.95	111	64	17	11	85	90	152	48	13	3.6	91	98	6.5	1.6
August	68	5.74	116	60	16	7	86	94	153	35	14	2.5	91	96	7.0	1.1
September	69	5.31	126	74	15	9	88	93	169	40	14	3.8	92	98	7.0	1.2
October	66	5.07	138	90	17	9.5	88	93	194	48	16	5.7	92	97	7.8	1.3
November	61	5.77	122	81	17	12	86	90	181	42	16	7.2	91	96	7.6	1.2
December	57	6.95	110	71	15	10	86	91	152	49	16	2.8	89	98	6.0	1.4
1974																
January	52	7.78	107	65	18	11	83	90	156	47	17	4.1	89	97	6.0	0.9
February	50	8.48	92	57	17	8	82	91	146	48	19	5.1	87	97	5.2	0.7
March	49	9.71	62	36	14	7.6	77	88	99	42	19	7.9	81	92	3.3	0.6
April	50	9.85	71	42	14	8	80	89	131	44	20	8.1	85	95	3.9	0.5
May	54	9.47	88	47	15	9	83	90	121	42	18	8.5	85	93	3.6	0.6
June	61	9.20	80	46	13	7	84	91	134	38	15	6.6	89	95	4.0	0.7
July	67	6.26	106	75	17	6	84	94	140	36	13	2.5	91	98	5.2	1.0
August	70	5.80	130	74	19	8	85	94	184	41	16	3.2	91	98	7.0	0.8
Averages		7.26	103	61	16	9	84	91	132	42	16	5.1	88	96	6.7	1.0

Note 1: Began chemical treatment June 1973.
Avg. dosage July 1973 to Aug. 1974: 42 mg/l $FeCl_3$ and 0.32 mg/l polymer.

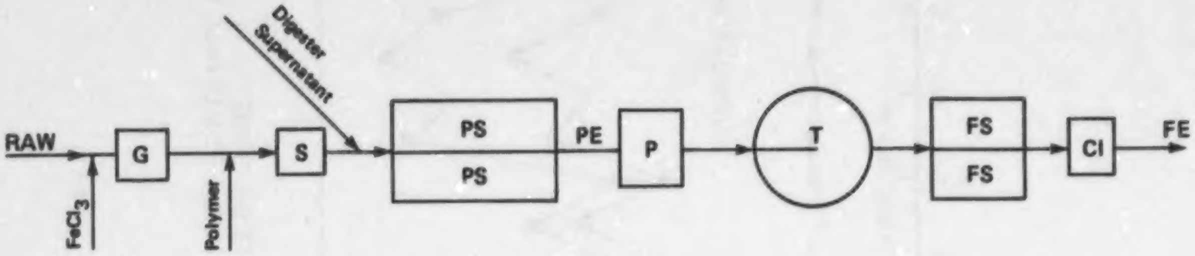
Note 2: MME = mixed media effluent.

FIG A-6
REMOVAL OF BOD
BY TWO-STAGE TRICKLING FILTERS AND MIXED MEDIA FILTERS
SHOWING EFFECT OF CHEMICAL TREATMENT
304, MICH



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
305, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTER

1 – 104 ft Diam – 6ft Deep
Area = 0.195 Acres ~ 8495 sqft
Volume = 51,000 cuft

Loading

Hydraulic @ 0.25 MGD (175 GPM Pump) – No R.

$$= \frac{0.25}{0.195} = 1.28 \text{ MGAD} \sim \frac{250{,}000}{8495} = 30 \text{ gals/sqft/day}$$

Organic @ 133 mg/l in PE

$$= \frac{0.25 \times 8.35 \times 133}{51} = 5.4 \text{ No./1000 cuft}$$

SLUDGE TREATMENT AND DISPOSAL

2 – 25 ft Diam Digesters
Volume = 20,000 cuft
Digested Sludge to open drying beds
Supernatant to raw sewage inlet

FINAL SETTLING TANK

1 – 10 ft x 30 ft x 10 ft Area = 300 sqft

$$\text{Surface Overflow Rate} = \frac{250{,}000}{300} = 833 \text{ gals/day/sqft}$$

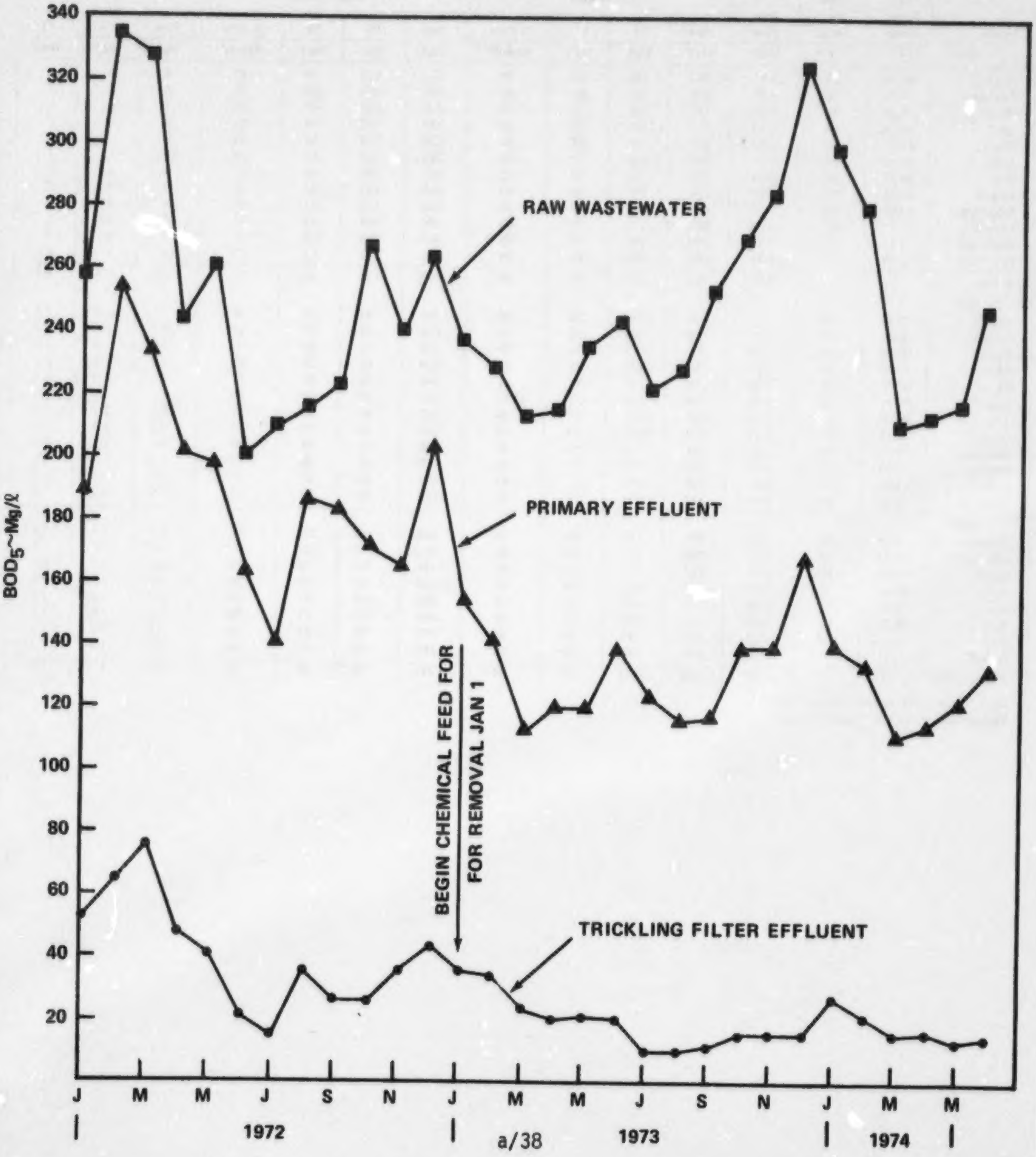
TABLE A-17
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS SHOWING EFFECT OF CHEMICAL TREATMENT
305 MICH.

Month	Air Temp. Range	Raw Sew. Temp.	Sew. Flow	5-Day BOD				Susp. Solids				Total P		
				Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.	Raw	PE	FE
1972	°F	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l
January	-20-30	57	0.21	258	189	53	79	272	112	33	88	8	6	5
February	-7-31	56	0.21	335	256	66	80	276	125	38	86	8	6	5
March	7-38	55	0.22	327	234	76	77	305	142	46	85	7	6	5
April	16-52	56	0.23	243	202	49	80	260	130	44	83	9	8	7
May	41-57	58	0.23	261	198	42	84	260	116	48	82	9	7	6
June	40-68	61	0.21	201	163	21	90	262	132	63	76	10	9	7
July	50-73	65	0.21	210	141	16	92	232	128	44	81	9	8	7
August	45-68	66	0.21	216	187	36	83	240	122	44	80	9	7	7
September	40-63	68	0.20	224	184	27	88	280	115	41	85	9	8	7
October	20-58	65	0.20	268	172	27	90	267	106	43	84	9	8	7
November	17-47	62	0.24	240	166	37	85	262	108	49	81	8	8	7
December	2-38	58	0.24	265	206	42	84	239	123	42	83	10	8	7
Average			0.22	264	191	41	84	263	122	46	83	8.7	7.4	6.4
1973														
January	0-33	56	1.25	238	156	36	86	286	82	33	88	7.7	2.6	1.4
February	-6-34	55	0.23	229	142	35	85	268	54	22	92	9.0	2.1	1.7
March	20-46	54	0.29	214	112	24	89	244	51	25	90	7.9	2.4	1.9
April	22-60	55	0.27	216	121	20	91	226	62	28	88	7.9	2.9	2.3
May	29-58	58	0.26	236	121	21	91	244	56	32	87	7.3	2.6	2.1
June	54-70	63	0.25	244	140	21	91	222	55	30	86	7.7	2.4	2.0
July	60-70	64	0.24	222	123	11	95	242	51	32	87	8.0	2.4	1.8
August	50-74	67	0.22	228	117	10	92	263	50	30	89	7.8	2.0	1.5
September	39-70	69	0.22	254	119	11	96	298	54	34	88	9.1	2.3	1.7
October	32-60	67	0.21	270	140	17	94	170	62	36	87	7.8	1.2	1.6
November	23-42	64	0.22	286	141	17	94	294	55	27	91	7.7	1.8	1.7
December	0-42	61	0.23	327	170	19	94	272	49	23	92	7.9	3.0	1.8
1974														
January	-5-34	56	0.26	298	141	29	90	256	40	24	91	6.3	1.4	1.3
February	-10-32	56	0.26	280	136	22	92	255	45	22	91	6.1	1.5	1.4
March	5-43	55	0.34	210	111	18	91	181	38	19	90	5.6	0.9	0.6
April	20-60	56	0.32	213	115	16	92	189	40	20	85	5.2	1.1	0.8
May	32-59	58	0.28	219	123	14	94	200	49	31	85	6.7	1.6	1.4
June	45-65	61	0.24	248	134	15	95	248	46	34	86	6.6	1.9	1.3
July		63	0.24	273	148	15	95	248	49	40	84	7.8	1.9	1.2
August		67	0.22	270	141	18	93	243	52	38	84	6.7	1.5	1.3
Average 1973–Aug. 1974			0.25	249	133	14	94	242	52	29	88	7.3	1.5	1.5

Note: Began chemical treatment Jan. 1973.

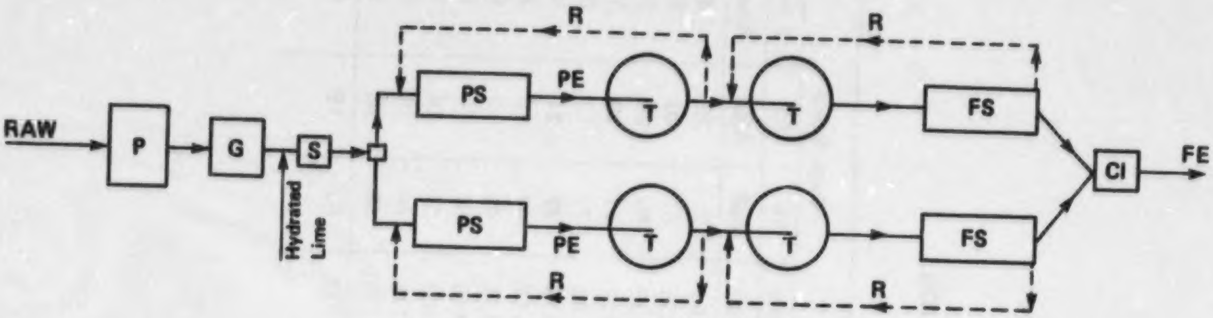
Dosage: 90# $FeCl_3$ and 1# polymer/day.

FIG A-7
REMOVAL OF BOD_5
TRICKLING FILTER PLANT
BEFORE AND AFTER CHEMICAL TREATMENT FOR PHOSPHORUS REMOVAL
305, MICH



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
PAW PAW LAKE, MICH
312

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS

Primary 2-60 ft diam 7 ft deep
Area = 0.130 Acres – 5655 sqft
Volume = 39,600 cuft
Loading on primary
Hydraulic @ 1.33 MGD

$$= \frac{1.33}{0.13} = 10.2 \text{ MGAD} \sim \frac{1,330,000}{5655} = 235 \text{ gals/day/sqft}$$

Organic @ 70 mg/l in PE

$$= \frac{1.33 \times 8.35 \times 70}{39.6} = 19.6\ \#/1000 \text{ cuft}$$

Loading on all filters (secondary same size as primary)
Hydraulic @ 1.33 MGD = 5.1 MGAD
Organic @ 70 mg/l in PE

$$= \frac{1.33 \times 8.35 \times 70}{79.2} = 9.8\ \#/1000 \text{ cuft}$$

FINAL SETTLING TANKS

2 – 25810 cuft Each; Total Surface Area = 4800 sqft

$$\text{Surface Overflow Rate} = \frac{1,330,000}{4800} = 277 \text{ gals/day/sqft}$$

CHEMICAL TREATMENT

Lime fed to rapid mix 1.5 minutes followed by 15 min aerated flocculation in primary clarifier

SLUDGE TREATMENT AND DISPOSAL

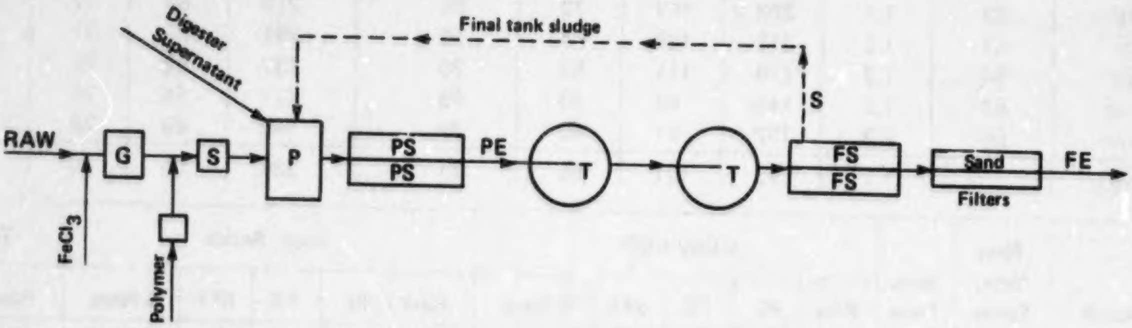
Lime treatment of raw sludge in thickening tanks
Filter Press
Filter cake hauled to orchards

TABLE A-18
REMOVAL OF BOD AND SUSPENDED SOLIDS
312 MICH.

Month	Flow MGD	Sew. Temp. °F	5-Day BOD				Susp. Solids			
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.
			Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
Jan	0.95	45	136	64	23	83	154	71	28	82
Feb	1.50	45	142	69	19	87	136	61	20	85
Mar	1.31	42	150	97	47	69	132	89	28	79
Apr	1.46	42	148	78	31	79	129	77	29	78
May	1.27	49	101	55	14	86	98	77	13	87
June	1.39	54	110	62	21	81	119	77	21	82
July	1.52	57	151	61	19	87	117	47	15	87
Aug	1.47	58	140	47	15	89	164	41	13	92
Sept	1.35	58	130	51	18	86	126	54	14	89
Oct	1.11	53	216	107	18	92	163	47	14	91
Nov	1.08	43	193	88	14	93	175	44	14	92
Dec	1.58	38	148	59	16	89	135	58	13	90
Avg	1.33	–	147	70	21	86	137	62	19	86

FACILITIES AND LOADINGS
TRICKLING FILTER-SAND FILTER PLANT
306, MICH

FLOW PATTERN


Digester Supernatant
Final tank sludge
S
RAW
G
S
P
PS
PS
PE
T
T
FS
FS
Sand
Filters
FE
FeCl3
Polymer

CAPACITIES AND LOADINGS

FILTERS

2 in Series 62 ft Diam 5'-6" Deep
Total Area = 0.138 Acres ~ 6038 sqft
Total Volume = 33,000 cuft

Loading

Hydraulic @ 2.19 MGD (R = 1.0 MGD Avg–FS Sludge)

$$= \frac{2{,}190{,}000}{6038} = 363 \text{ gals/day/sqft}$$

Organic @ Av. Flow = 1.2 MGD; BOD in PE = 67 mg/l

$$= \frac{1.2 \times 8.35 \times 67}{33} = 20.3\ \#\text{BOD}_5/1000 \text{ cuft}$$

SAND FILTERS

2 Beds each 12.5 ft by 50 ft = 1250 sqft

Loading

Hydraulic @ 3.0 MGD (MAX)

$$= \frac{3{,}000{,}000}{1250} = 2400 \text{ gals/day/sqft} = 1.67 \text{ gals/min/sqft}$$

Organic @ 24 mg/l in Filter Effluent

$$= \frac{1.2 \times 8.35 \times 24}{1250} = 0.20\ \#\text{BOD}_5/\text{sqft/day}$$

SLUDGE TREATMENT AND DISPOSAL

1 – Primary – 12500 cuft ; 1 – Secondary – 12,400 cuft
Digested Sludge to filter press & open drying beds

PHOSPHORUS REMOVAL

Feed points (see flow pattern)
$FeCl_3$ @ 30-35 mg/l
Polymer @ 0.5-0.75 mg/l

TABLE A-19
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS BY TRICKLING FILTERS AND SAND FILTERS WITH CHEMICAL TREATMENT
306 MICH.

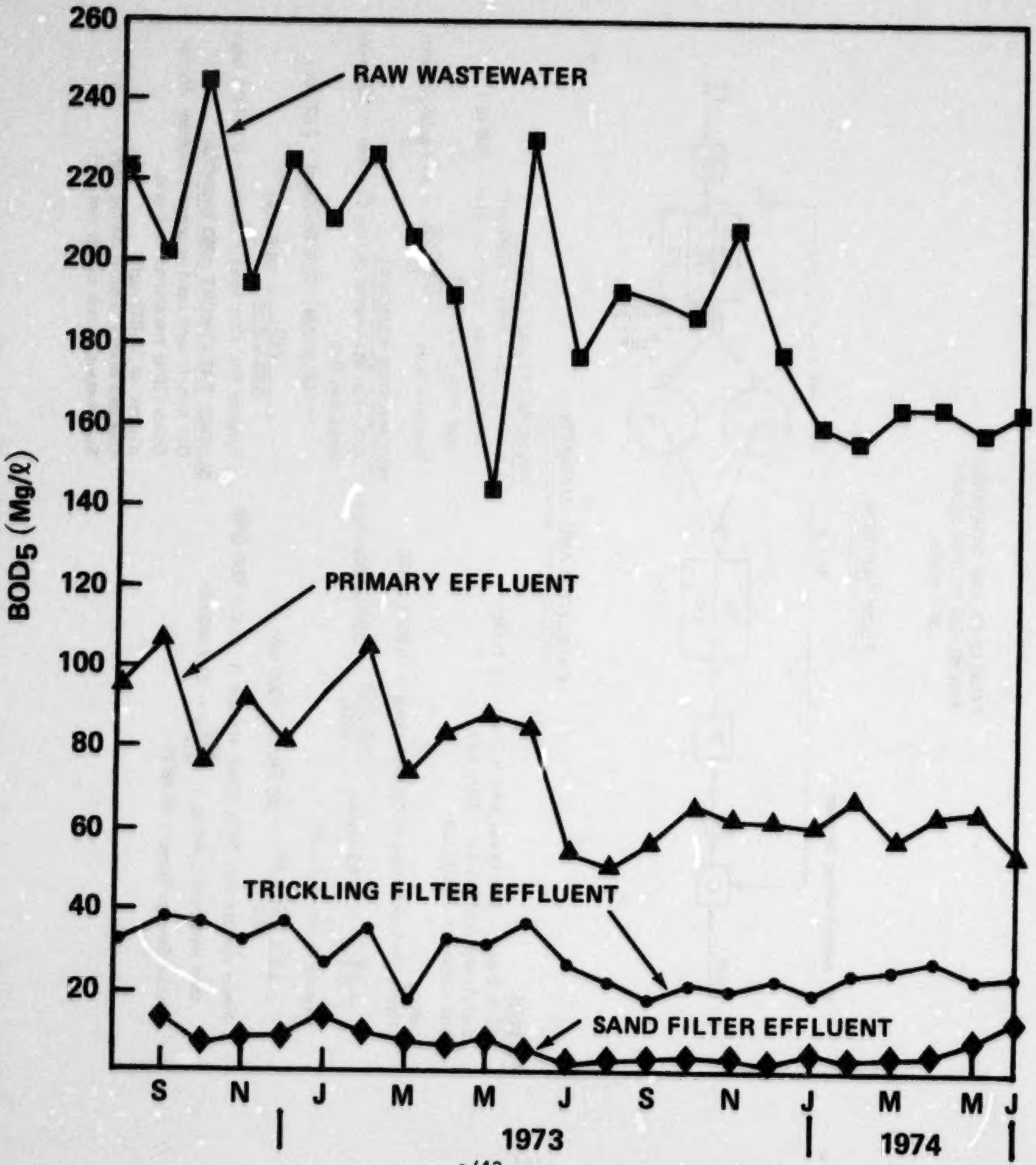
Month	Raw Sew. Temp.	Sew. Flow	5-Day BOD				Susp. Solids			
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.
(1972)	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
Jan	54	1.2	229	145	77	66	386	137	51	87
Feb	53	1.1	208	157	72	65	219	84	47	79
Mar	53	1.2	213	128	64	70	251	109	37	85
Apr	54	1.2	179	111	53	70	137	52	27	80
May	57	1.2	140	84	30	79	211	56	25	88
June	59	1.2	192	97	40	79	140	69	29	79
Avg.		1.2	193	121	56	71	224	85	36	84

Month	Raw Sew. Temp.	Sew. Flow	5-Day BOD					Susp. Solids					Total P	
			Raw	PE	FE	SFE	% Rem.	Raw	PE	FE	SFE	% Rem.	Raw	FE
(1973-4)	°F	MGD	Mg/l	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l
June	62	1.2	230	85	37	6	81	279	47	16	5	94	NR	NR
July	65	1.2	176	54	27	2	85	294	45	12	4	96	NR	NR
Aug	66	1.1	193	50	22	3	89	160	37	14	4	94	7.1	1.9
Sept	67	1.0	190	56	22	3	88	271	40	14	2	95	8.8	1.4
Oct	64	1.0	187	65	21	4	89	339	58	16	4	95	NR	NR
Nov	61	1.0	208	62	20	3	90	281	50	13	3	95	16.4	3.2
Dec	57	1.0	176	61	22	2	88	204	48	19	4	91	8.8	2.6
Jan	54	1.3	158	60	20	3	87	169	60	15	4	91	6.4	1.9
Feb	52	1.2	155	65	24	4	85	204	56	37	6	82	6.1	2.2
Mar	52	1.4	164	57	25	3	85	145	65	17	5	93	7.1	3.0
Apr	54	1.4	163	63	28	6	83	219	47	16	4	93	9.9	2.6
May	57	1.3	158	64	23	9	85	199	44	20	5	90	9.1	3.6
Avg		1.2	180	62	24	4	87	247	50	17	5	93	8.9	2.5

Overall plant removal: BOD_5 = 98^+% ; Susp. Sol. = 98%

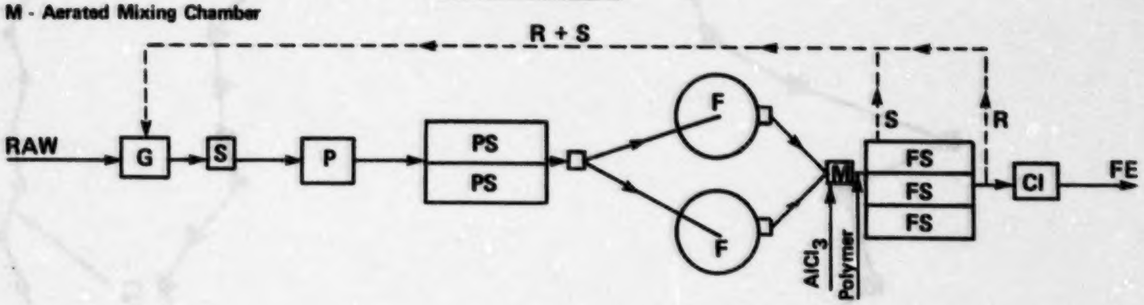
Note: Chemical treatment began 1973.

FIG A-8
REMOVAL OF BOD$_5$
TRICKLING FILTER-SAND FILTER PLANT
306, MICH



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
307. MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS

1-45 ft Diam. – 6 ft Deep; 1-65 ft Diam. – 6 ft Deep
Total Area = 0.113 Acres = 4908 sqft
Total Volume = 29,400 cuft

Loading
Hydraulic @ Av. Flow (0.65 MGD) plus R (0.95 ± MGD)

$= \frac{1.6}{0.113} = 14.2$ MGAD ; $\frac{1{,}600{,}000}{4908} = 326$ gals/day/sqft

Organic @ 44 mg/l in PE

$= \frac{1.6 \times 8.35 \times 44}{29.4} = 20\ {}^{\#}BOD_5/1000$ cuft

Winter operate only 45 ft Filter; Reduce R so Q = 550 GPM

then Hydraulic Loading $= \frac{0.78}{0.036} = 21.7$ MGAD

(Winter Sewage Temp = 36-38°F)

FINAL SETTLING TANKS

1-45 ft Diam. Area = 1590 sqft
2 – Rectangular combined Area = 768 sqft
Total Area = 2358 sqft

Overflow Rate $= \frac{1{,}600{,}00}{2358} = 675$ gals/day/sqft

PHOSPHORUS REMOVAL

$AlCl_3$ Fed to Aerated Mixing Chamber ~ 10± mins.
Detention Rate

= 100 gals/day (25% Solution) = $210^{\#}$/day

$= \frac{210}{0.65 \times 8.35} = 38.5$ mg/l

Polymer Fed after Mixing Chamber @ 0.4-0.6 mg/l

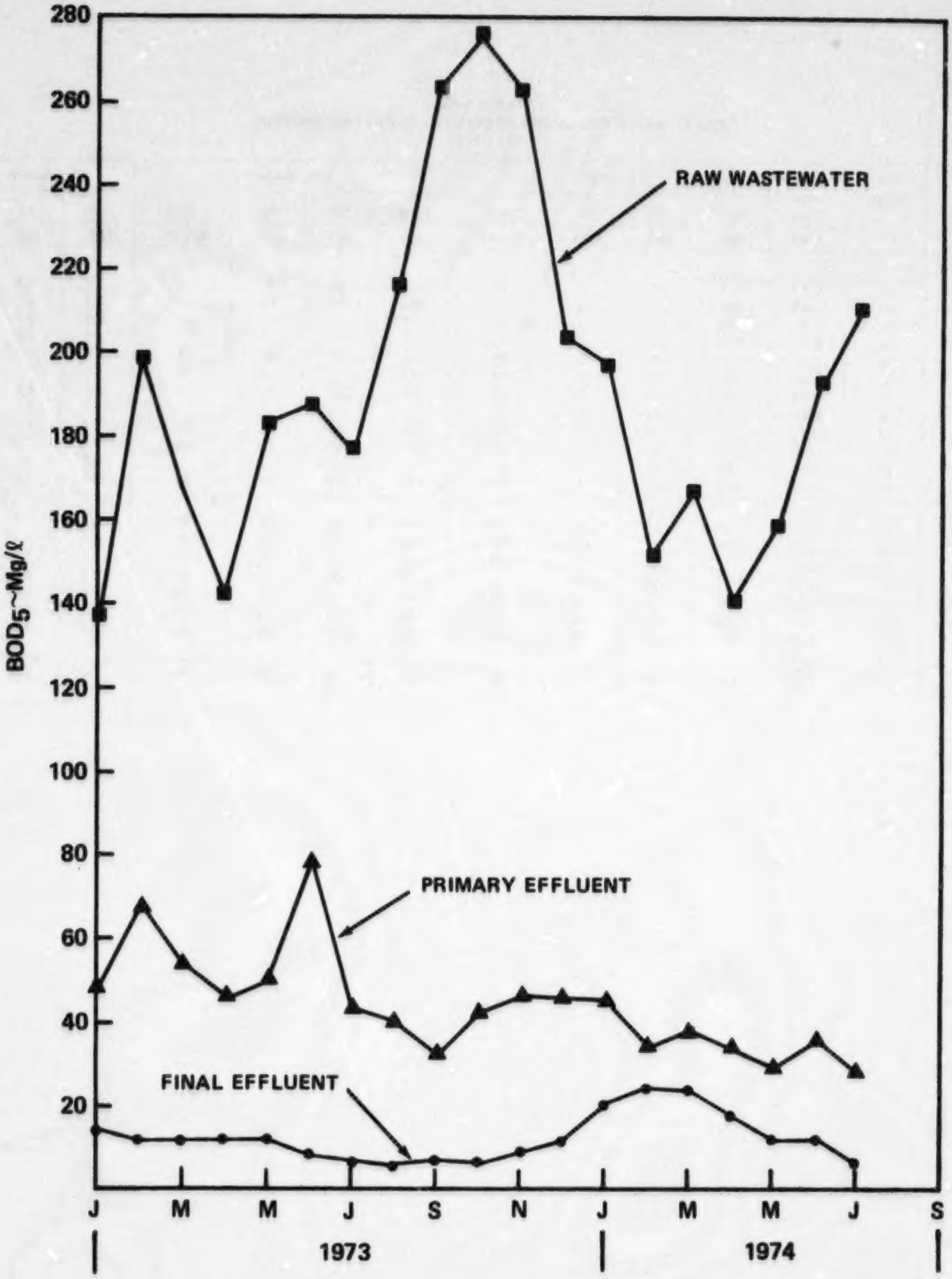
SLUDGE TREATMENT AND DISPOSAL

Old Imhoff tank used as primary digester. Sludge Solids (10%) transferred to heated digester of 15,830 cuft
Digested sludge to open drying beds
Supernatant to raw sewage wet well

TABLE A-20
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS
307 MICH.

Month	Sew. Temp.	Raw Sew. Flow	5-Day BOD				Susp. Solids				Total P.		
			RAW	PE	FE	% Rem.	RAW	PE	FE	% Rem.	RAW	PE	FE
	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l
1973													
January	52	0.72	137	49	14	90	144	69	34	76	5.8	2.6	1.0
February	52	0.58	198	67	12	94	200	107	41	80	7.2	3.1	0.7
March	51	0.85	165	54	12	93	183	98	39	79	7.1	3.7	0.8
April	54	0.76	141	46	12	91	–	–	–		7.3	3.8	0.8
May	56	0.74	184	50	11	94	148	106	32	78	6.9	4.2	0.6
June	63	0.64	187	79	9	95	173	–	29	83	–	–	0.7
July	66	0.50	177	43	8	95	183	142	25	86	9.0	5.9	0.7
August	68	0.46	217	40	6	97	–	–	–		10.2	4.1	0.5
September	68	0.45	262	31	7	97	224	51	29	87	11.6	1.2	0.8
October	67	0.45	275	42	7	97	251	57	27	89	12.0	2.0	0.7
November	62	0.53	261	47	9	97	–	–	–		9.7	2.2	0.7
December	56	0.61	203	47	11	95	175	79	32	82	8.4	3.0	0.6
1974													
January	51	0.77	97	46	21	58	170	49	30	82	8.0	1.7	0.7
February	49	0.72	151	33	24	84	148	35	25	83	6.7	1.1	0.7
March	50	0.91	165	38	24	79	138	38	25	82	5.6	1.3	0.7
April	51	0.90	141	34	18	87	132	33	21	84	5.5	1.2	0.6
May	55	0.69	158	29	12	92	150	35	17	89	7.0	1.4	0.7
June	60	0.51	193	35	12	94	169	36	19	89	8.7	1.4	0.7
July	67	0.46	210	28	7	97	220	47	20	91	10.1	1.5	0.8
August													
Averages		0.65	190	44	12	94	175	65	28	84	8.2	2.5	0.7

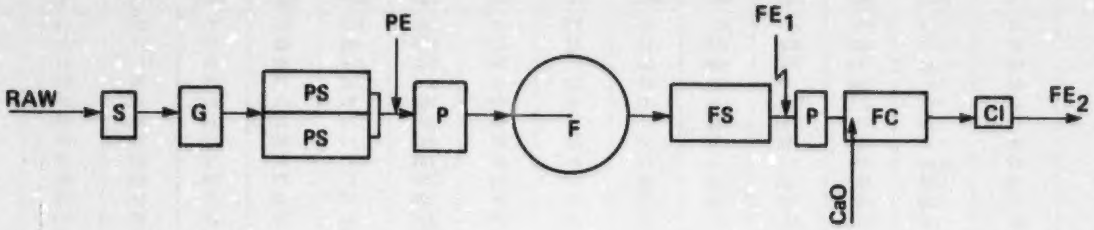
FIG A-9
REMOVAL OF BOD$_5$ THROUGH PLANT TRICKLING FILTER PLANT WITH CHEMICAL TREATMENT FOR PHOSPHORUS REMOVAL
307, MICH



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
308, MICH

FLOW PATTERN

FC - Flocculater-Clarifier (Upflow)



CAPACITIES AND LOADINGS

FILTER

1-104 ft Diam 6.5 ft Deep

Area = 8495 sqft = 0.195 Acres

Volume = 55000 cuft

Loading @ Avg Flow = 1.36 MGD & 163 Mg/l in PE

Hydraulic @ 1.36 MGD ~ No recirculation

$$= \frac{1.36}{0.195} = 7.0 \text{ MGAD}; \frac{1{,}360{,}000}{8495} = 160 \text{ gals/day/sqft}$$

Organic @ 163 Mg/l in PE

$$= \frac{1.36 \times 8.35 \times 163}{55} = 33.7^{\#}/1000 \text{ cuft}$$

SLUDGE TREATMENT & DISPOSAL

Lime treated sludge pumped to Lime Sludge Lagoons.

Lagoon Area = 321,600 sqft – Depth 2.5 ft.

CHEMICAL TREATMENT FOR PHOSPHORUS REMOVAL

Lime fed to Flocculator-clarifier for sludge treatment and phosphorus removal

Feed rate = $2400^{\#}$/day as CaO dry weight

FINAL SETTLING TANK

1-55 ft Diam; Area = 2375 sqft; Volume = 191,000 gals

$$\text{Surface Overflow Rate} = \frac{1{,}360{,}000}{2375} = 573 \text{ gals/day/sqft}$$

TABLE A-21
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS
308 MICH.

Month (1975)	Raw Sew. Temp. °F	Sew. Flow MGD	5-Day BOD						Susp. Solids						Total P
			Raw	PE	FE_1	FE_2	% Removal		Raw	PE	FE_1	FE_2	% Removal		FE_2
			Mg/l	Mg/l	Mg/l	Mg/l	Raw-FE_1	Raw-FE_2	Mg/l	Mg/l	Mg/l	Mg/l	Raw-FE_1	Raw-FE_2	Mg/l
Jan	61	1.38	241	207	107	50	56	79	200	107	53	15	74	93	1.6
Feb	57	1.37	234	204	112	43	52	82	178	106	52	18	71	90	2.3
Mar	56	1.34	218	178	106	55	51	75	202	136	58	16	71	92	1.1
Apr	60	1.41	228	173	107	46	53	80	216	108	76	21	65	90	1.6
May	66	1.34	218	161	86	38	60	83	188	82	41	22	78	88	2.3
June	72	1.28	202	136	59	31	71	85	221	74	32	22	86	90	2.6
July	75	1.32	222	155	58	37	74	83	223	73	30	19	87	91	2.4
Aug	77	1.44	199	144	40	29	80	85	194	79	31	19	84	90	2.8
Sept	74	1.35	232	158	30	16	87	93	231	77	27	28	88	88	2.6
Oct	73	1.39	231	158	34	25	85	89	224	97	42	31	81	86	2.6
Nov	69	1.34	216	146	26	20	88	91	263	93	39	21	85	92	4.8
Dec	60	1.34	242	136	33	23	86	90	316	73	32	19	90	94	4.6
Avg	–	1.36	224	163	67	34	70	85	221	92	43	21	81	90	2.6

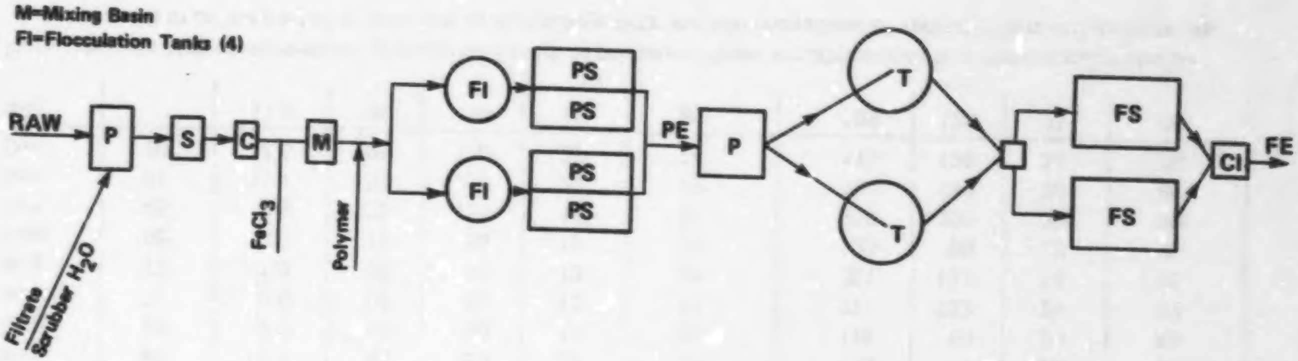
Note:

FE_1 = Final settling tank effluent before addition of lime

FE_2 = Effluent from flocculator-clarifier after lime addition

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
314, MICH

FLOW PATTERN


M=Mixing Basin
FI=Flocculation Tanks (4)
RAW
P
S
C
M
FeCl3
Polymer
Filtrate
Scrubber H2O
FI
FI
PS
PS
PS
PS
PE
P
T
T
FS
FS
Cl
FE

CAPACITIES AND LOADINGS

FILTERS (Plastic Media)

2-74′ Diam 21.5′ Deep
Total Area = 8600 sqft = 0.197 Acres
Total Volume = 184,900 cuft

Loading

Hydraulic @ Avg Flow = 11.97 MGD ~ Recirculation consists of final settling tank sludge, vacuum filter filtrate, scrubber water etc ~ approx. 0.5 MGD

$$= \frac{11{,}970{,}000}{8600} = 1390 \text{ gals/day/sqft}; \quad \frac{11.97}{0.197} = 60 \text{ MGAD}$$

Organic @ 79 mg/l BOD_5 in PE

$$= \frac{11.97 \times 8.35 \times 79}{185} = 42^{\#}/1000 \text{ cuft}$$

FINAL SETTLING TANKS

2-110′ Diam 12′ SWD
Total Area = 19000 sqft
Surface Overflow Rate @ 11.97 MGD

$$= \frac{11{,}970{,}000}{19{,}000} = 630 \text{ gals/day/sqft}$$

CHEMICAL FOR PHOSPHORUS REMOVAL

Points of application $FeCl_3$ to inlet to parshall flume followed by rapid mixer; Polymer to flume after mixing basin followed by coagulation tanks

Dosage Rates
$FeCl_3$ – Avg 50 mg/l
Polymer–0.5-0.8 mg/l

SLUDGE TREATMENT AND DISPOSAL

Vacuum Filters
Incineration
Ash to Lagoons

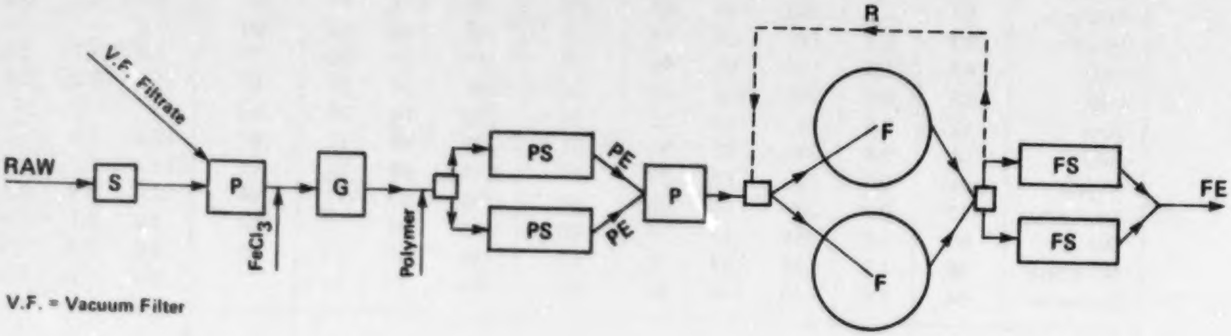
TABLE A-22
REMOVAL OF BOD AND SUSPENDED SOLIDS
314 MICH.

Month	Raw Sew. Temp	Sew. Flow	5-Day BOD				Suspended Solids			
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.
	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE
Jan	48	10.5	78	100	21	73	164	105	45	73
Feb	46	9.8	94	66	20	79	140	75	41	71
Mar	49	11.2	86	43	17	80	130	75	19	85
Apr	52	13.0	75	62	18	75	139	57	22	84
May	63	11.1	85	69	21	75	124	71	20	84
June	68	12.3	85	60	13	85	116	80	20	83
July	71	9.6	64	50	15	77	277	133	21	92
Aug	72	11.9	90	82	13	86	281	163	14	95
Sept	66	13.6	79	56	12	85	120	95	13	89
Oct	65	9.8	139	131	18	57	203	200	20	90
Nov	61	11.4	103	115	23	78	194	344	29	85
Dec	50	14.5	95	110	25	74	140	138	34	76
Avg		11.6	89	79	18	80	169	128	25	85

Note: Periodic high concentrations of suspended solids in primary effluent are attributable to extensive accumulation of solids in primary settling tanks due to high outage time and low production of vacuum filters and incinerators.

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
310, MICH

FLOW PATTERN



V.F. = Vacuum Filter

CAPACITIES AND LOADINGS

FILTER (Plastic Media)

2 – 38'-8" Diam. ~ 21.5' Deep
Total Area = 2348 sqft = 0.054 Acres
Total Volume = 50,500 cuft

Loading

Hydraulic @ 1.6 MGD + R =(2.75 MGD)= 4.35 MGD

$$= \frac{4350000}{2348} = 1850 \text{ gals/sqft/day} = \frac{4.35}{0.054} = 80 \text{ MGAD}$$

Organic @ 54 mg/l BOD_5

$$= \frac{1.6 \times 54 \times 8.35}{50.5} = 14.3\ \#BOD_5/1000 \text{ cuft}$$

PHOSPHORUS REMOVAL

Chemical feed (see flow pattern)

$FeCl_3$ - 40 mg/l; Polymer - 0.5 - 1.0 mg/l

FINAL SETTLING TANKS

2 – 45 ft Diam ~ Surface Area = 3180 sqft
Surface Overflow Rate = 1.6 MGD

$$\frac{1{,}600{,}000}{3180} = 503 \text{ gals/day/sqft}$$

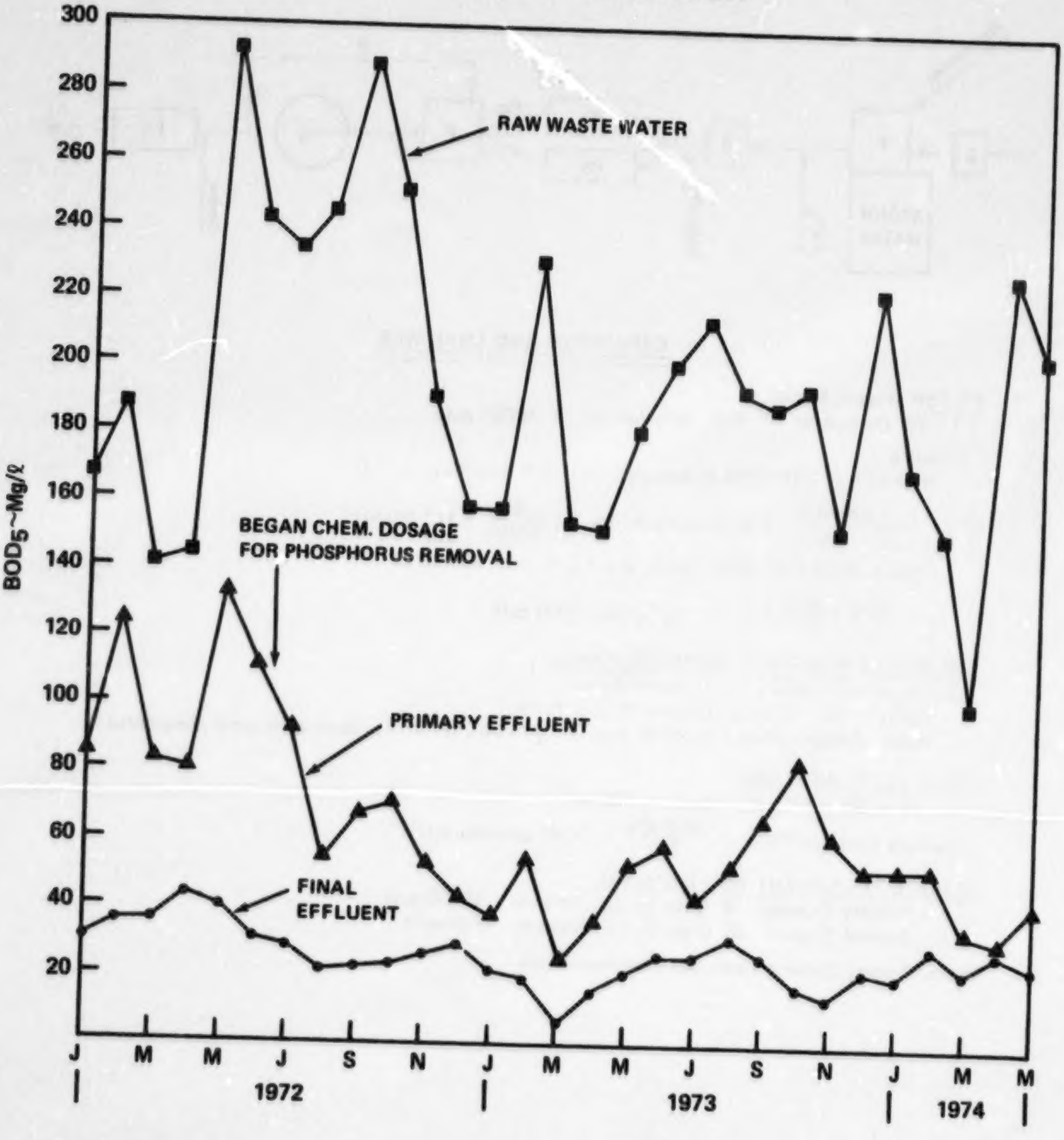
SLUDGE TREATMENT AND DISPOSAL

1 – Primary Digester ~ 21,200 cuft
1 – Secondary Digester ~ 21,200 cuft
1 – Vacuum Filter & open Sludge Drying Beds
Sludge to Sanitary Landfill
Supernatant & Filtrate to Raw Sewage Pump Station

TABLE A-23
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS
310 MICH.

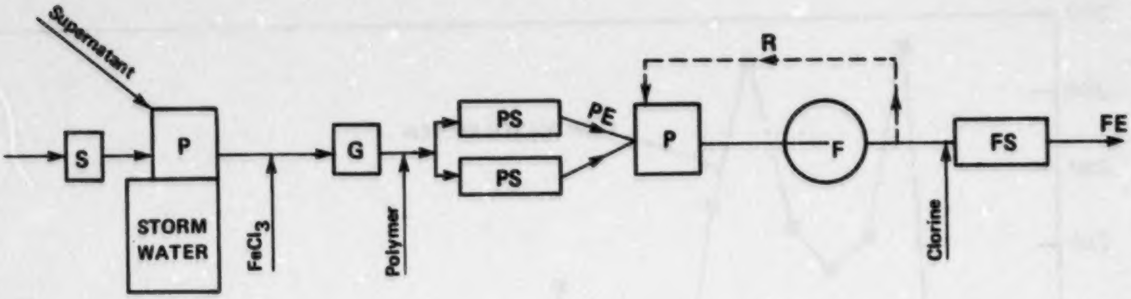
Month	Raw Sew. Temp.	Sew. Flow	5-Day BOD				Susp. Solids				Total P		
			RAW	PE	FE	% Rem.	RAW	PE	FE	% Rem.	RAW	PE	FE
	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l
1972													
January	52	1.4	166	86	31	81	210	86	36	83	7.8	3.9	2.8
February	52	1.0	188	123	37	80	266	111	41	85	8.0	5.6	3.2
March	50	2.1	141	84	37	74	264	120	53	80	7.8	3.9	2.4
April	47	1.0	145	81	45	69	149	71	35	77	7.8	4.9	2.9
May	53	0.5	294	135	42	86	261	124	37	86	11.5	9.3	7.0
June	52	0.5	243	112	33	86	237	94	33	86	–	–	–
July	60	0.4	234	93	30	87	217	64	17	92	12.0	2.4	1.2
August	61	0.4	245	56	24	90	234	42	20	91	12.7	1.7	0.9
September	62	0.7	289	69	25	91	266	43	17	94	10.4	3.4	2.5
October	61	0.9	251	72	26	90	175	38	11	94	7.9	2.1	1.6
November	59	1.2	186	54	28	85	169	33	13	92	6.9	1.4	1.3
December	54	1.6	158	44	30	81	146	32	11		6.7	1.2	1.4
1973													
January	49	2.3	158	38	24	85	154	30	11	92	5.2	1.2	1.0
February	50	1.1	232	57	21	91	253	33	11	96	8.7	1.4	1.0
March	47	4.1	154	25	8	95	246	24	11	96	5.0	0.9	0.8
April	49	2.1	152	37	17	89	181	35	10	94	5.3	1.3	0.8
May	52	1.4	181	53	21	88	123	38	17	86	6.4	1.9	1.4
June	56	1.5	201	59	28	86	214	41	19	91	8.6	3.8	2.1
July	59	1.0	213	44	28	87	245	40	15	94	11.8	1.9	2.0
August	62	0.8	193	53	32	83	163	51	13	92	10.0	5.0	4.0
September	63	1.0	189	67	29	85	127	41	10	92	11.9	3.9	3.7
October	63	0.9	195	85	19	90	149	33	12	92	9.0	2.1	1.6
November	61	1.1	153	62	16	90	154	29	11	93	11.7	2.3	2.0
December	54	1.8	223	53	24	89	148	24	13	91	9.0	1.8	1.0
1974													
January	50	2.1	170	53	15	91	100	21	9	91	5.5	1.0	1.0
February	48	1.9	152	54	25	84	133	40	12	91	5.5	2.7	1.0
March	46	3.0	102	36	17	83	97	23	11	89	3.4	1.9	0.6
April	50	2.9	229	32	18	92	329	30	7	98	6.2	1.1	1.2
May	54	1.7	212	41	22	90	272	26	8	97	7.8	1.5	1.2
June		1.1	195	70	21	89	198	41	8	96	8.8	2.7	1.6
July		1.1	235	78	20	91	227	62	12	95	10.4	3.4	2.0
August		0.9	259	77	18	93	210	44	15	93	10.0	1.5	1.5
Average 1973-1974		1.6	190	54	21	89	186	35	12	94	8.0	2.2	1.6
Averages Jan-June 1972—before chemical treatment		1.1	196	104	38	81	231	101	39	83	8.6	5.5	3.6
Averages Jan-June 1947—after chemical precipitation well established		2.0	177	49	20	89	188	30	9	95	6.2	1.8	1.1

FIG A-23
REMOVAL OF BOD_5
310, MICH. TRICKLING FILTER PLANT
SHOWING IMPROVEMENT
WITH CHEMICAL TREATMENT



FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
309, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTER (Plastic Media)

1 - 30′ Diam;Area = 700 sqft;Volume = 15000 cuft

Loading

Hydraulic @ 1300 GPM (Constant Rate); R @ Avg Flow = 1.0

$$= \frac{1,870,000}{700} = 2670 \text{ gals/sqft/day} = \frac{1.87}{0.016} = 117 \text{ MGAD}$$

Organic @ 23 mg/l BOD$_5$ in PE and Avg Flow = 0.94 MGD

$$= \frac{0.94 \times 8.35 \times 23}{15} = 12\ \#\text{BOD}_5/1000 \text{ cuft}$$

CHEMICALS FOR PHOSPHORUS REMOVAL

Points of Application ~ See Flow Pattern

$FeCl_3$ ~ 40 - 50 mg/l ; Polymer 0.25-0.35 mg/l

Note: Dosage reduced to 20-25 mg/l in 1975-76 with similar removal of total phosphorus

FINAL SETTLING TANK

1 - 14′ x 50′ x 11′ - 6″ Area = 700 sqft

$$\text{Surface Overflow Rate} = \frac{940,000}{700} = 1340 \text{ gals/day/sqft}$$

SLUDGE TREATMENT AND DISPOSAL

1 – Primary Digester 34′ Diam by 20′ Volume = 18000 cuft

1 – Storage Digester 20′ Diam by 14′ Volume - 4400 cuft

Note: Primary Settling Tanks are Clariflocculators

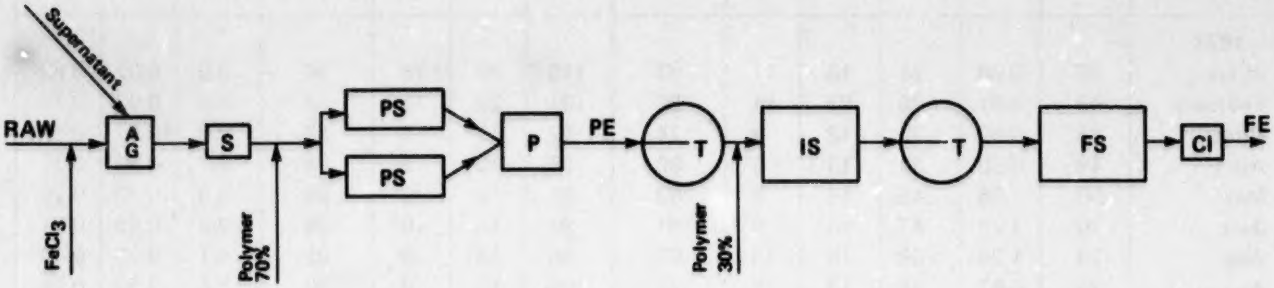
TABLE A-24
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS
309 MICH.

Month	Raw Sew. Temp.	Sew. Flow	5-Day BOD				Susp. Solids				Total P		
			RAW	PE	FE	% Rem.	RAW	PE	FE	% Rem.	RAW	PE	FE
	°F	MGD	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l
1972													
September	71	0.94	81	13	6	91	139	14	11	92	5.4	0.26	0.3
October	65	0.95	58	16	7	88	89	14	12	87	5.5	0.62	0.6
November	55	1.03	52	15	9	83	92	20	14	85	4.2	0.54	0.6
December	49	1.10	62	17	8	87	209	20	12	94	4.8	0.79	0.6
1973													
January	46	0.98	64	16	11	83	110	27	18	84	3.9	0.97	0.89
February	46	0.81	70	27	14	80	107	22	11	90	5.4	0.92	0.71
March	45	0.85	35	12	9	74	82	19	15	82	2.8	0.52	0.50
April	49	0.80	30	13	6	80	55	10	12	78	2.7	0.24	0.37
May	58	1.36	46	15	8	83	61	10	9	85	3.3	0.30	0.26
June	70	1.23	47	13	9	81	97	13	10	90	2.8	0.19	0.21
July	73	1.30	58	16	10	83	96	13	8	92	4.1	0.21	0.19
August	76	0.97	56	13	13	77	90	10	8	90	3.5	0.23	0.26
September	75	0.94	62	19	12	81	152	13	8	95	4.6	0.33	0.31
October	66	0.63	109	45	14	87	82	25	13	84	9.0	0.89	0.46
November	58	0.82	102	42	12	88	77	28	8	90	8.5	0.69	0.62
December	52	0.85	95	27	13	86	86	15	9	90	5.7	0.43	0.43
1974													
January	51	0.89	92	29	18	80	44	12	9	80	3.3	0.44	0.36
February	46	0.94	91	35	13	86	70	18	10	86	4.9	0.40	0.41
March	46	1.19	62	21	15	76	44	12	9	80	3.3	0.44	0.41
April	49	Flow	69	16	10	86	65	12	8	88	4.1	0.28	0.29
May	54	Meter	115	30	16	86	136	19	9	93	5.9	0.35	0.29
June	60	Out	113	32	13	88	183	32	11	94	7.0	0.46	0.26
July	70	0.67	108	32	13	88	89	20	9	90	6.8	0.39	0.35
August	71	0.59	121	44	14	88	121	28	16	95	7.8	0.56	0.70
Average		0.94	75	23	11	85	99	18	11	89	5.0	0.48	0.43

Chemical Dosage:
    $FeCl_3$ – Avg. 44 mg/l
    Polymer – Avg. 0.3 mg/l

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
311, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS (Plastic Media)

2 – 32.33′ x 27′

Total Area = 1745 sqft = 0.040 Acres

Total Volume = 1475 x 21.6′ = 37,690 cuft

Loading

Hydraulic @ 1.1 MGD (variable speed pump); No R.

$$= \frac{1,100,000}{1745} = 630 \text{ gals/sqft} \; ; \; \frac{1.1}{0.04} = 27.5 \text{ MGAD}$$

Organic @ 56 mg/l in PE

$$= \frac{1.1 \times 8.35 \times 56}{37.7} = 13.6 \text{ lbs } BOD_5/1000 \text{ cuft.}$$

CHEMICALS FOR PHOSPHORUS REMOVAL

Points of Application ~ See Flow Pattern

$FeCl_3$ – 55 mg/l Dosage ; Polymer 0.35 mg/l

FINAL SETTLING TANK

1 – 50′ Diam. Area = 1960 sqft

Surface Overflow Rate

$$= \frac{1,100,000}{1960} = 560 \text{ gals/day/sqft}$$

SLUDGE TREATMENT AND DISPOSAL

2 – Primary Digesters – Total Volume = 25,200 cuft

1 – Final Digester ~ Volume = 12,600 cuft

Vacuum Filter

Supernatant & Filtrate returned to primary settling tanks

Note: Intermediate Settling Tank Same Size as Final Settling Tank

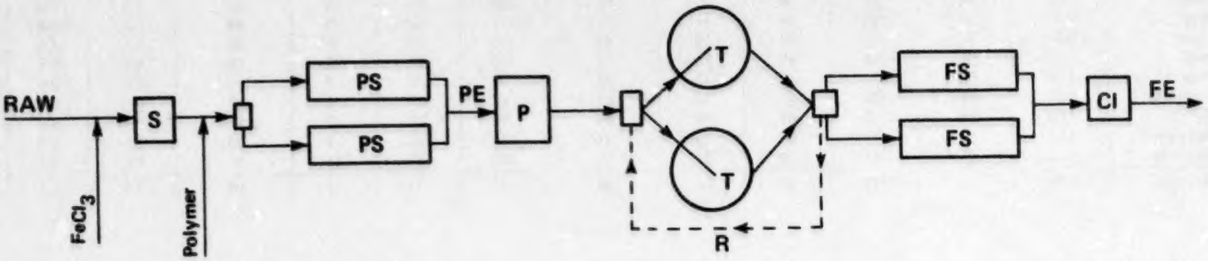
Abbrev: AG = Aerated grit chamber

TABLE A-25
REMOVAL OF BOD, SUSPENDED SOLIDS AND PHOSPHORUS
311 MICH.

Month 1975	Flow MGD	Sew. Temp. °F	5-Day BOD				Susp. Solids				Total P	
			Raw	PE	FE	% Rem.	Raw	PE	FE	% Rem.	Raw	FE
			Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l
January	0.97	50	116	67	26	78	102	38	16	84	6.6	0.7
February	0.93	50	113	68	25	78	95	42	19	80	6.8	0.5
March	1.03	49	127	70	26	80	131	44	18	86	6.6	0.6
April	1.10	52	123	56	24	80	108	41	15	86	7.4	0.6
May	0.97	59	129	53	19	85	111	39	13	88	8.3	0.8
June	0.99	64	130	53	18	86	110	39	11	90	8.1	1.0
July	1.00	68	145	45	13	91	123	43	12	90	8.3	0.9
August	1.18	68	117	49	16	86	98	30	8	92	7.0	0.5
September	1.30	65	102	42	14	85	87	37	8	91	6.2	0.8
October	1.00	64	128	57	19	85	96	39	11	86	8.1	0.9
November	1.03	59	113	50	18	81	114	34	8	93	7.5	0.6
December	1.09	53	141	58	22	84	109	30	11	90	6.4	0.7
Averages	1.05	–	121	56	20	83	107	39	12	89	7.3	0.7

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
313, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTER (Plastic Media)
2 – 21.5' x 21.5' deep
Total Area = 725 sqft = 0.017 Acres
Total Volume = 15610 cuft

Loading

Hydraulic @ 700 GPM (constant rate) R = $\frac{1.0 - 0.35}{0.35}$ = 1.8

$= \frac{1000000}{725}$ = 1380 gals/day/sqft = 59 MGAD

Organic @ Avg Flow = 0.35 MGD and 60 mg/l BOD_5 in PE

$= \frac{0.35 \times 8.35 \times 60}{15.6}$ = 11 #BOD_5/1000 cuft

CHEMICALS FOR PHOSPHORUS REMOVAL
Points of Application – See Flow Pattern
Dosage
$FeCl_3$ – 30-40 mg/l
Polymer – 0.1 – 0.3 mg/l

FINAL SETTLING TANKS
2 – 34 -8" Diam 9' SWD
Total Surface Area = 1890 sqft

Surface Overflow Rate

$= \frac{1,000,000}{1890}$ = 530 gals/sqft/day

SLUDGE TREATMENT AND DISPOSAL

Raw sludge stored in storage tank and transferred to regional plant. Decant to pump station.

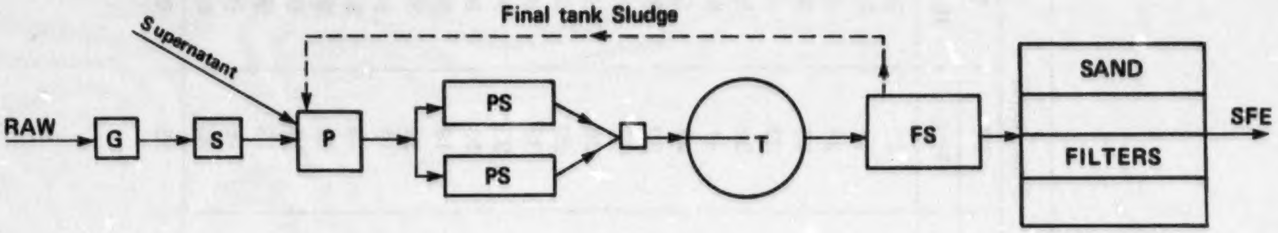
TABLE A-26
REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS
TRICKLING FILTER PLANT
313 MICH.

Month	Flow	BOD$_5$			Susp. Solids		
	MGD	RAW	FE	%	RAW	FE	%
(1974-75-76)		Mg/l	Mg/l	Rem.	Mg/l	Mg/l	Rem.
August	0.20	191	20	90	378	22	94
September	0.15	233	25	89	419	17	96
October	0.12	211	24	91	537	28	95
November	0.18	215	23	89	371	26	93
December	0.35	133	31	77	295	33	89
January	0.44	130	24	82	253	38	85
February	0.48	114	26	77	262	51	81
March	0.47	125	24	81	273	47	83
April	0.45	136	23	83	251	32	87
May	0.37	126	18	86	277	24	91
June	0.36	148	23	84	280	30	89
July	0.24	147	22	85	279	20	93
August	0.29	140	28	80	332	33	90
September	0.40	128	22	83	226	23	90
October	0.23	168	24	86	327	15	95
November	0.28	148	23	84	414	18	96
December	0.45	125	32	74	267	32	88
January	0.30	130	31	76	299	19	94
February	0.72	94	22	77	260	18	93
March	0.67	82	17	79	253	22	91
April	0.40	135	18	87	306	13	96
May	0.42	119	17	85	344	13	96
June	0.23	159	10	94	450	16	96
July	0.17	160	14	91	384	20	95
Averages	0.35	148	23	84	322	25	92

Note: Limited data on primary effluent indicates approx. 50% removal.

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
169, MICH

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTER

1 – 50' Diam
Area = 1960 sqft = 0.045 Acres
Volume = 12000 cuft

Loading
Hydraulic @ 0.5 MGD Pump Rate

$$= \frac{500{,}000}{1960} = 255 \text{ gals/day/sqft}; \quad \frac{0.5}{0.045} = 11 \text{ MGAD}$$

@ 0.78 MGD Pump Rate = 400 gals/day/sqft

Organic @ Avg Flow = 0.5 MGD and 64 mg/l BOD_5 in PE

$$= \frac{0.5 \times 8.35 \times 64}{12} = 22\ ^{\#}/1000 \text{ cuft}$$

FINAL SETTLING TANK

1 – 45' Diam. 8'-0" SWD
Surface Area = 1590 sqft
Surface Overflow Rate @ 0.5 MGD

$$= \frac{500{,}000}{1590} = 315 \text{ gals/day/sqft}$$

SLUDGE TREATMENT AND DISPOSAL

1 – Digester 35' Diam 30' SWD
Volume = 29000 cuft
Digested sludge to open drying beds
Supernatant to pump station

INTERMITTENT SAND FILTERS (open)

4 beds 120' x 80' each; 9" Graded gravel 1/8" – 1"; 24" sand eff. size 0.6-0.9 mm: U.C. < 2.5
Operate only in Summer – about May-Oct.
Dose Intermittently – fill & draw – dry out – cultivate
Loading @ 0.5 MGD

$$= \frac{500{,}000}{4 \times 9600} = 13 \text{ gals/day/sqft} = \frac{0.5 \times 8.35 \times 40}{9.6 \times 4} = 4/^{\#}\text{day/sqft}$$

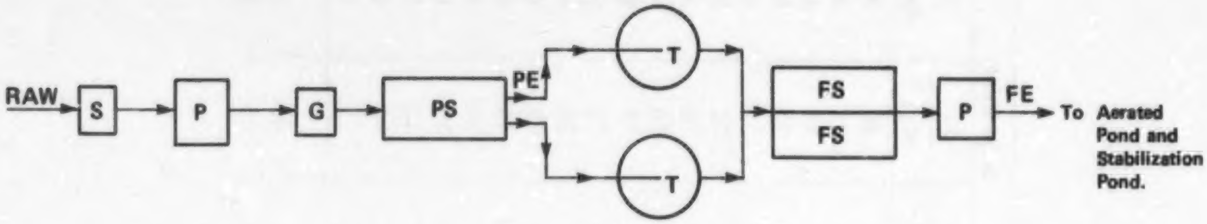
TABLE A-27
REMOVAL OF BOD$_5$ AND SUSPENDED SOLIDS BY TRICKLING FILTERS AND SAND FILTERS
170 MICH.

Month	Sew. Flow	BOD$_5$				Susp. Solids		
		Raw	PE	FE	%	Raw	FE	%
1975-76	MGD	Mg/l	Mg/l	Mg/l	Rem.	Mg/l	Mg/l	Rem.
Jan	0.49	87	66	46	47	90	49	46
Feb	0.47	95	69	47	51	105	48	54
Mar	0.59	95	62	40	58	112	48	57
Apr	0.70	76	61	32	58	95	33	65
May	0.50	79	55	31	61	85	32	62
June	0.42	99	61	*8	92	187	*9	95
July	0.43	86	54	*6	93	125	*9	93
Aug	0.33	94	58	*8	91	105	*8	92
Sept	0.35	104	66	*6	94	103	*7	93
Oct	0.39	94	65	*9	90	90	*8	91
Nov	0.40	116	69	41	65	121	38	69
Dec	0.40	113	70	41	64	118	39	67
Jan	0.41	122	80	44	64	137	44	68
Feb	0.71	96	65	43	55	114	35	69
Mar	0.91	83	55	31	63	97	35	64
Apr	0.82	82	63	*8	90	98	*10	90
May	0.56	86	65	*9	90	89	*11	88
June	0.46	96	69	*8	92	105	*8	92
Avg:								
(Tr. Filter)	0.52	96	64	40	58	107	40	63
(Sand Filter)	0.47	93	63	8	91	113	9	92

*Sand filter effluent following trickling filter and its final settling tank.

FACILITIES AND LOADINGS
TRICKLING FILTERS & PONDS
117, MINN

FLOW PATTERN



LOADINGS AND CAPACITIES

FILTERS (2)

1-97′ Diam (ROCK) Area = 7390 sqft = 0.17 Ac; Vol = 59120 cuft
1-51′ Diam (TILE) Area = 2040 sqft = 0.047 Ac; Vol = 12240 cuft
Total Area = 9430 sqft = 0.216 Ac; Vol = 71360 cuft

Loading

Hydraulic @ 1MGD

$$= = \frac{1{,}000{,}000}{9430} = 106 \text{ gals/day/sqft} = 4.6 \text{ MGAD}$$

Organic @ 0.93 MGD and 168 mg/l in PE

$$= \frac{0.93 \times 168 \times 8.35}{71.36} = 18.3\ {}^{\#}\text{BOD}_5/1000 \text{ cuft}$$

FINAL SETTLING TANK

2-20 x 60 = 2400 sqft
Surface Overflow Rate @ IMGD

$$= \frac{1{,}000{,}000}{2400} = 416 \text{ gals/day/sqft}$$

SLUDGE TREATMENT AND DISPOSAL

1-Digester Vol = 25,288 cuft
Digested sludge to sludge storage tank to lagoons

AERATED POND

Area = 3 Acres ~ 6′ Deep floating aerator 15 HP
Detention @ 1.0 MGD = Approx 25 days

STABILIZATION POND

Area = 25 Acres ~ 3′ Deep
Detention @ IMGD = Approx 25 days
Effluent distributed by piping to 20 acre peat absorption bed

TABLE A-28
REMOVAL OF BOD AND SUSPENDED SOLIDS
117 MINN.

Month	Sew. Flow	5-Day BOD			Susp. Solids		
		Raw	FE	% Rem.	Raw	FE	% Rem.
	MGD	Mg/l	Mg/l	Raw-FE	Mg/l	Mg/l	Raw-FE
Jan	0.90	270	38	86	251	38	85
Feb	0.86	224	42	81	239	42	82
Mar	1.10	240	39	84	239	33	86
Apr	0.82	229	44	81	238	33	86
May	0.88	280	35	88	242	29	88
June	0.94	250	46	82	280	44	84
July	1.06	260	48	82	272	33	88
Aug	0.96	270	36	87	212	42	80
Sept	0.93	271	36	87	262	31	88
Oct	1.00	302	39	87	230	34	85
Nov	0.95	288	40	86	225	30	87
Dec	0.83	242	37	85	233	49	79
Avg	0.93	259	40	85	243	37	85

Note:

For Tertiary Treatment results, see Table A-29

Assuming 35% removal in primary settling tanks,
PE = 0.65 x 259 = 168 mg/l 5-day BOD

TABLE A-29
REMOVAL OF BOD_5 & SUSP. SOLIDS
TRICKLING FILTERS & PONDS
117 MINN.

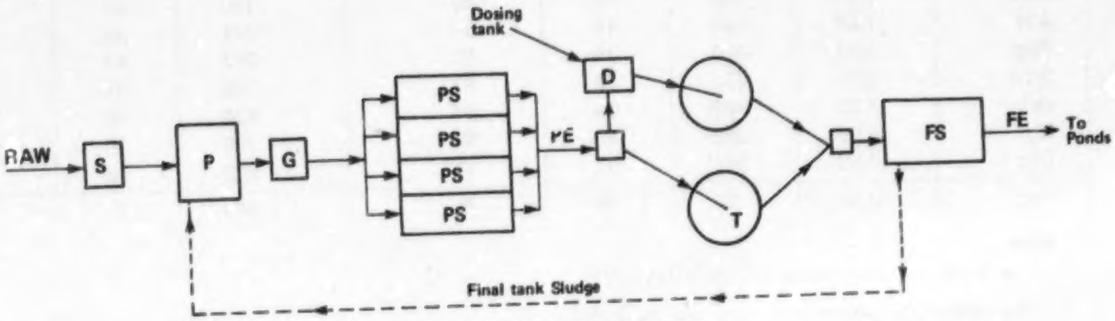
Month	Flow	BOD_5 ~ Mg/l				Susp. Solids ~ Mg/l			
	MGD	Raw	FE	AP	SP	Raw	FE	AP	SP
Jan	0.90	270	38	27	10	251	38	19	7
Feb	0.86	224	42	20	7	239	42	14	9
Mar	1.10	240	39	18	8	239	33	14	6
Apr	0.82	229	44	24	15	238	33	17	20
May	0.88	280	35	15	4	242	29	31	5
June	0.94	250	46	19	3	280	44	31	4
July	1.06	260	48	11	7	272	33	16	6
Aug	0.96	270	36	10	11	212	42	15	11
Sept	0.93	271	36	12	4	262	31	24	6
Oct	1.00	302	39	21	4	230	34	15	4
Nov	0.95	268	40	19	5	225	30	10	5
Dec	0.83	242	37	15	2	233	49	10	1
Avg	0.93	259	40	18	7	243	37	18	7

Abbreviations:

AP - Aerated Pond Effluent
SP - Stabilization Pond Effluent
FE - Trickling Filter Effluent

FACILITIES AND LOADINGS
TRICKLING FILTER PLANT
121, N. DAKOTA

FLOW PATTERN



CAPACITIES AND LOADINGS

FILTERS

1 – 220′ x 135′ (Fixed Nozzles) 9′ deep
1 – 148′ Diam. (Rotary) 9 deep
Total Area = 46,900 sqft = 1.08 Acres
Total Volume = 422,000 cuft

Loading (2-5 MGD Pumps & 1 Variable Speed)
Hydraulic @ 5 MGD Pumping Rate

$$= \frac{5{,}000{,}000}{46{,}900} = 106 \text{ gals/day/sqft}; \ 4.63 \text{ MGAD}$$

@ 10 MGD Pumping Rate

$$= \frac{10{,}000{,}000}{46{,}900} = 213 \text{ gpd/sqft}$$

Organic @ Avg Flow = 5.85 MGD and 140 mg/l in PE

$$= \frac{5.85 \times 8.35 \times 140}{422} = 16.2 \text{ lbs/1000 cuft}$$

FINAL SETTLING TANK

1 – 110′ Diam Area · 9500 sqft
Surface Overflow Rate @ Avg Flow = MGD

$$= \frac{6{,}000{,}000}{9500} = 630 \text{ gals/day/sqft}$$

SLUDGE TREATMENT AND DISPOSAL

2 – Primary Digesters 75′ Diam – Volume = 176,000 cuft
2 – Secondary Digesters 55′ Diam – Volume = 46,000 cuft
Supernatant returned directly to primary settling tank
Digested sludge to open drying beds – underdrains to pumping station.

OXIDATION PONDS

6 Lagoons Each 90 Acres
Total Area 540 Acres
Operate 5 in parallel, discharge each in turn to No. 6, hold and discharge to river
Time required to fill @ 6 MGD & 4′ depth

$$= \frac{90 \times 43560 \times 4 \times 7.5}{6{,}000{,}000} = 20 \text{ Days}$$

Hold another 10-20 days before discharge
No discharge during winter months

TABLE A-30
REMOVAL OF BOD_5 AND SUSPENDED SOLIDS BY TRICKLING FILTERS AND LAGOONS
121 N. DAKOTA

Month	Sewage Flow	Lagoon Dischg. to River	BOD_5			Susp. Solids		
			Raw	FE	LE	Raw	FE	LE
1975-76	MGD	MG	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l
Nov	5.41	556.6	233	53	6	194	49	15
Dec	4.91	255.4	208	62	9	178	42	13
Jan	5.10	0	238	66	–	181	46	–
Feb	5.45	0	231	57	–	191	48	–
Mar	6.66	0	238	54	–	199	64	–
Apr	6.53	242.3	242	60	15	189	55	15
May	6.09	256.6	205	59	12	134	43	11
June	6.38	-	202	50	–	178	49	–
July	6.25	263.3	198	43	11	164	39	10
Aug	5.93	0	227	48	–	168	37	–
Sept	5.78	275.2	206	64	10	179	42	11
Oct	5.77	445.0	214	59	9	177	44	18
Avg	5.86	191.2	220	56	10	178	47	13

Total Annual Sewage Flow = 2139 million gals.
Total Annual Discharge from Lagoons = 2294 million gals.

Removals by Plant & Lagoons
- Plant: BOD_5 75%; Susp. Solids 74%
- Lagoon: BOD_5 82%; Susp. Solids 72%
- Plant & Lagoon: BOD_5 95^+%; Susp. Solids 93^-%

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